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Magnetostatic Wave Channelizer (MSWC) Evaluation

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13. ABSTRACT (*Maximum 200 words*)

This report describes the test and evaluation of the Magnetostatic Wave Channelizer (MSWC). The MSWC was developed for Electronic Warfare (EW) systems and applications. The motivation for MSWC resulted from a need for wide instantaneous bandwidth and large dynamic range. Various performance parameters of the device were evaluated, including bandwidth, sensitivity, dynamic range, and the selectivity bandwidth. Other MSWC characteristics measured were two tone intermodulation, blocking, desensitization, and simultaneous emitters.

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MAGNETOSTATIC WAVE CHANNELIZER (MSWC) EVALUATION

1. INTRODUCTION

The Magnetostatic Wave Channelizer (MSWC) was developed under ONR sponsorship to evaluate the feasibility of using magnetostatic technology for channelizer applications. The Naval Research Laboratory (NRL) provided technical support for development of the MSW Channelizer with the Electronics Science and Technology Division performing development functions and the Tactical Electronic Warfare Division (TEWD) providing performance requirements as well as Channelizer Test and Evaluation (T&E). The MSW Channelizer development spanned 1989 through 1994 and the T&E phase was completed in 1996.

1.1 Development Motivation

NRL's interest in MSWC technology was a response to the need for wide instantaneous bandwidth and large dynamic range in EW systems. Electromagnetic environment signals from many sources occupy a large spectral range, and EW systems require rapid signal detection. Therefore, the wide bandwidth feature of the MSWC constitutes a valuable signal processing potential. Also, EW systems require signal detection and exploitation in environments in which low level threat signals are in range with higher level nearby signals. Appropriately, the MSWC high dynamic range characteristic offers the ability to detect weaker signals as well as simultaneously transmitted more powerful signals. Finally, the MSWC is smaller, lighter, and uses less power than currently deployed channelizers.

1.2 Development Accomplishments

Several MSWC receiver functions were developed during the evolution and evaluation period. A single 500 MHz quadrant of the MSWC was assembled and evaluated, although the overall channelizer design used four contiguous 500 MHz frequency quadrants to cover a total of 2 GHz. The 3.0 to 3.5 GHz MSWC quadrant was evaluated using both pulsed and continuous wave (CW) signals for testing. Multiple simultaneous signals were applied to determine the MSWC selectivity and multiple signal reporting that included two equal power level signals as well as signals of widely different power levels.

1.3 Performance Summary

Table 1 shows the major MSWC performance characteristics determined during T&E as well as the corresponding receiver design goals. Although two MSWC frequency demultiplexor quadrants were fabricated, only one quadrant was operational. The 500 MHz frequency span of the developed MSWC equipment, vice the 2.0 GHz receiver design goal, sufficiently demonstrated the capabilities and limitations of MSW channelization for EW applications.

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Table 1 — Summary of MSWC Performance

MSWC Characteristics	MSWC Equipment	Receiver Design
Instantaneous Bandwidth	500 MHz	2000 MHz
Input Frequency Range	3.0 to 3.5 GHz	3.0 to 5.0 GHz
Sensitivity Power Level Range	-40 dBm	- 85 dBm
Dynamic Range	50 dB	50 dB
Selectivity Bandwidth (50 dB signal separation)	50 MHz	60 MHz

MSWC sensitivity was measured at -40 dBm nominally, although sensitivity in some channels reached -46 dBm. Receiver sensitivity is increased by implementing low noise preamplification (i.e., before the channelizer) in the MSWC, therefore sensitivity will approach the receiver requirement by adding low noise amplification. A nominal measured MSWC dynamic range of 50 dB addresses the corresponding receiver design requirements. In channels where MSWC sensitivity extends below -40 dBm, the dynamic range also exceeds 50 dB. The ability of MSWC to detect and characterize sensitivity level signals in the presence of interfering maximum dynamic range signals was demonstrated with a signal separation as close as 50 MHz.

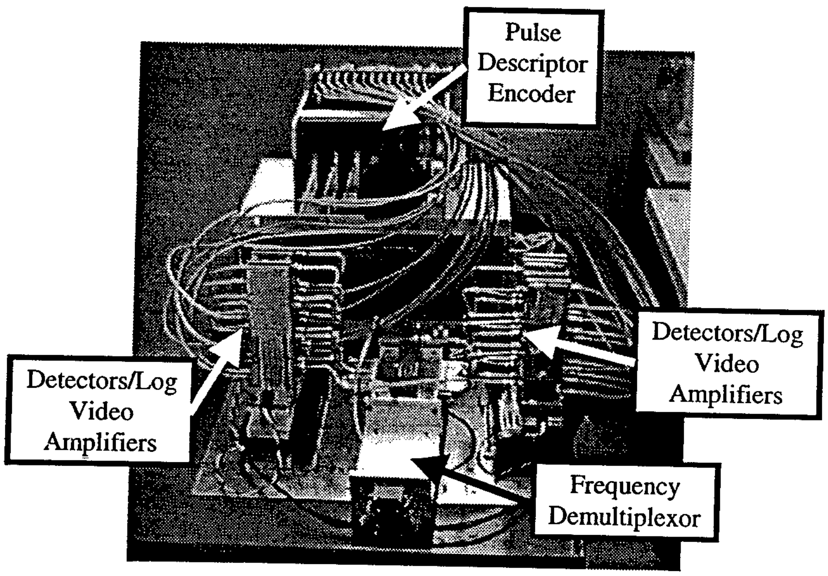

Fig. 1 —MSWC Equipment

1.4 Equipment

Figure 1 shows the MSWC equipment. The equipment is a brassboard designed for laboratory demonstration. The MSWC Frequency Demultiplexor is enclosed in a precision-machined housing along with the MSWC circuits and the high permittivity permanent magnets. A single wideband 3.0 to 3.5 GHz RF port drives the MSWC Frequency Demultiplexor. Twenty-seven 20-MHz channel-bandwidth RF output ports are provided on the MSWC Frequency Demultiplexor to drive the channelizer detector and log video amplifiers to transform the 50 dB input dynamic range to a reasonable signal processing range. The log video analog output drives the pulse descriptor encoder, which performs signal detection and qualification. The signal is then digitized and formatted for output transfer.

1.5 Evaluation Summary

MSWC evaluation revealed its strengths and weaknesses vs design requirements. The limited MSWC operating bandwidth was established with only casual observation. In addition, frequency linearity anomalies were noted in several regions of the operating bandwidth. The MSWC evaluation showed inoperative channels within the operating frequency band, and resulting frequency domain irregularities observed included channel numeric order reversal and large variations in channel bandwidth. The realized MSWC size and weight physical features achieved were as anticipated and MSWC demonstrated good selectivity in multiple signal testing. This MSW technology shows great potential for high performance in electronic support measures (ESM). However, considerable engineering is required to realize the MSWC receiver performance goals.

1.6 Evaluation Report Summary

The remainder of this report provides a brief description of MSWC and discusses the test program in detail. Section 2 provides a summary of the test results. In Section 3, a description of MSWC is provided as a summary definition of the equipment evaluated. The functional elements of MSWC are provided to indicate the interaction and interrelationship between the magnetostatic frequency demultiplexor and the electronic interface to the remainder of the system. Section 4 explicitly describes and analyzes the MSWC tests performed. Correspondingly, Section 5 presents a detailed description of the characterization test plans used in obtaining the data. Section 6 offers conclusions, recommendations, and observations addressing tradeoffs and options necessary to move MSWC technology forward into operational use.

2. SUMMARY OF TEST RESULTS

MSWC Test and Evaluation offers insight into the technology maturity in relation to the performance necessary for successful operational deployment. MSWC performance measurements included sensitivity, dynamic power range, pulse rate capability, two-tone intermodulation and frequency resolution, blocking, desensitization, simultaneous emitter detection, and CW emitter reception capability.

2.1 Performance Characteristics

Table 2 details the performance characteristics of the MSWC as determined during testing. A summary description of the T&E results follows.

Table 2 — Performance Characteristics of the MSWC

	Minimum	Maximum	Mean	Std. Deviation
Operating Bandwidth	3.0 GHz	3.5GHz		
Sensitivity Power Levels	-46 dBm	+10 dBm	-40.33 dBm	2.57 dB
Inoperative Frequency	3.15 GHz	3.20 GHz		
Segments	3.45 GHz	3.50 GHz		
Channel Order	1-7, 9, 8, 12-21, 23, 22			
Channel Bandwidth	5.4 MHz	24 MHz	16.086 MHz	4.48 MHz
Desensitization Percentages	-2%	-45%		

The MSWC covered its 3.0 to 3.5 GHz operating bandwidth with the exception of several inoperative frequency channels. Anomalies in MSWC frequency coverage included inoperative channels and instances of channel frequency reversal. As seen in Table 2, the specific spectral segments that were inoperative are from 3.15 to 3.2 GHz and from 3.45 to 3.5 GHz. MSWC measured signals across power levels ranging from a minimum value (most sensitive) of -46 dBm to a maximum power level of +10 dBm. The average measured sensitivity was -40.33 dBm with a standard deviation of 2.57 dB (see Section 4.1 for details). The actual appearance of channels is also listed in Table 2 under Channel Order. It is noted that channels 9, 8, 22, and 23 are out of numeric order, and that channels 10, 11, 0, and 24 are inoperative. Also listed are the measured channel bandwidths. Note that the average channel bandwidth is within one standard deviation of the design channel bandwidth of 20 MHz. Finally, the table notes the desensitization percentages when a desensitizing signal was introduced during testing. The MSWC received signal probability of intercept was reduced between 2% and 45% when subjected to a desensitizing signal compared to nominal MSWC sensitivity.

2.2 Sensitivity Characteristics

The Sensitivity Test measured the minimum RF input power level into the MSWC that provided a reliable signal detection and measurement (i.e., the MSWC received all applied pulses). The test signal was sequentially applied at 1 MHz frequency intervals across the MSWC bandwidth, and the emitter signal power was initialized at -60 dBm and increased by 1 dB until all applied pulses were detected (Section 4.1 provides further details). The expected power level at which all pulses were received was -40.33 dBm with a standard deviation of 2.57 dB and a minimum sensitivity power level of -46 dBm.

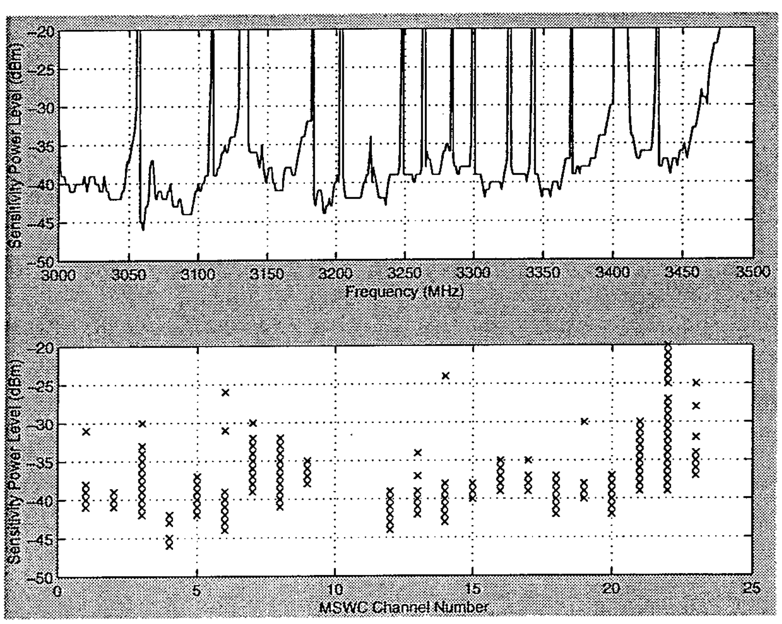

Fig. 2 — Sensitivity power level vs applied frequency

Figure 2 shows the Sensitivity Power level readings as a function of applied input signal frequency as well as MSWC channel number. The applied input signal frequency spans 3.0 to 3.5 GHz. The fluctuations in sensitivity power level within single channels as well as between different channels are shown here. As shown, the Sensitivity Power levels are centered about a nominal level of about –40 dBm across the frequency band. Exceptions are seen between the MSWC channels as spikes in the sensitivity power. Also, by examining the Sensitivity Power levels vs the MSWC channel number, voids can be discerned in channels 9 (3.18 to 3.2 GHz), 10 (3.2 GHz), 23 (3.46 to 3.48 GHz), and 24 (3.48 to 3.5 GHz).

2.3 Dynamic Range Characteristics

The MSWC dynamic range was measured in the RF Power Test. A signal, similar to that applied in the Sensitivity Test, is applied over a range of power levels from 3 dB below the sensitivity power to a maximum of +10 dBm (Section 4.2 provides further details). Measured received signal amplitudes were in units of V_{REL}, the relative voltage measured out of the MSWC detector circuitry. For these measurements, the high power dynamic range measurements are established by a maximum generator power level of 10 mW (+10 dBm), since no hard limited saturation was observed in MSWC testing.

Figure 3 shows the MSWC transfer characteristic, representing the channelizer dynamic operating range, and the interchannel uniformity resulting from the RF Power Test data. Each frequency channel has a slightly different transfer curve. A least-squares fit line was generated for each set of frequency data. The mean transfer curve, as well as the standard error estimate (shown by the error bars), were calculated and are shown in Fig. 3.

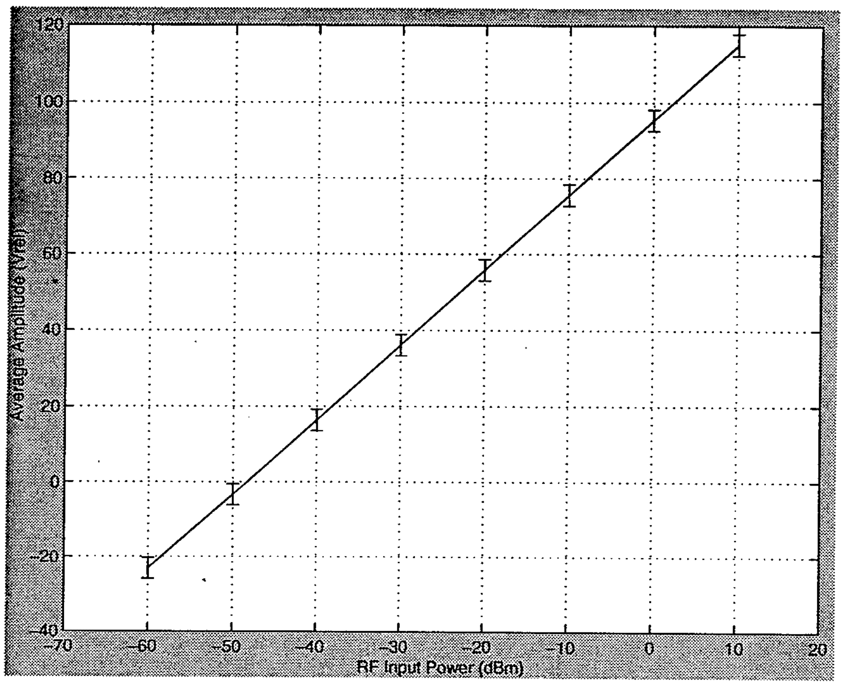

Fig. 3 — MSWC transfer characteristic and interchannel uniformity

2.4 Pulse Rate Characteristics

The Pulse Rate Capability Test measured the MSWC's ability to detect signals with short pulse repetition intervals (PRIs) at various pulse widths. A maximum of four PRIs was applied at each of three different frequencies (Section 4.3 provides further details). The MSWC showed a higher probability of detection with the smaller pulse widths/pulse repetition interval combinations than with large intervals.

2.5 Two-Tone Intermodulation Characteristics

The Two-Tone Intermodulation Test determined the performance of the MSWC when simultaneous copulse signals are present within the active bandwidth. Dual copulse emitter signals with frequencies selected to provide intermodulation products in various channels within the active bandwidth were employed to evaluate MSWC intermodulation performance. However, MSWC intermodulation products were not observed with the maximum (10 mW) power levels applied. MSWC response to the applied signals was confined to channel filter leakage through the channel filter nearest the signal in frequency. No intermodulation products were observed (Section 4.4 provides further details).

2.6 Two-Tone Frequency Resolution Characteristic

The MSWC's ability to receive signals in the presence of a high level copulse interfering signal was evaluated using the Two-Tone Frequency Resolution Test. Two signals were applied simultaneously: one signal was applied at the MSWC center frequency and maximum power, and the other signal was stepped through the frequency bandwidth at various power levels (Section 4.5 provides further details). It was observed that the variable frequency signal disappeared under interference from the high level signal when the variable signal operated at low power levels and frequency approached that of the high level signal.

Figure 4 demonstrates channelizer filter selectivity performance. As power is increased at the second emitter, pulses are detected on either side of the first emitter frequency. As the maximum power level is applied to the second emitter, a high probability of detection occurs over a wide portion of the channelizer spectral range extending to the channels adjacent to the first emitter frequency. Detections from Emitter 2 are observed closer to the center frequency of Emitter 1 as the power is increased. Figure 4 also shows that the MSWC detects Emitter 2 over several spectral segments at constant power levels.

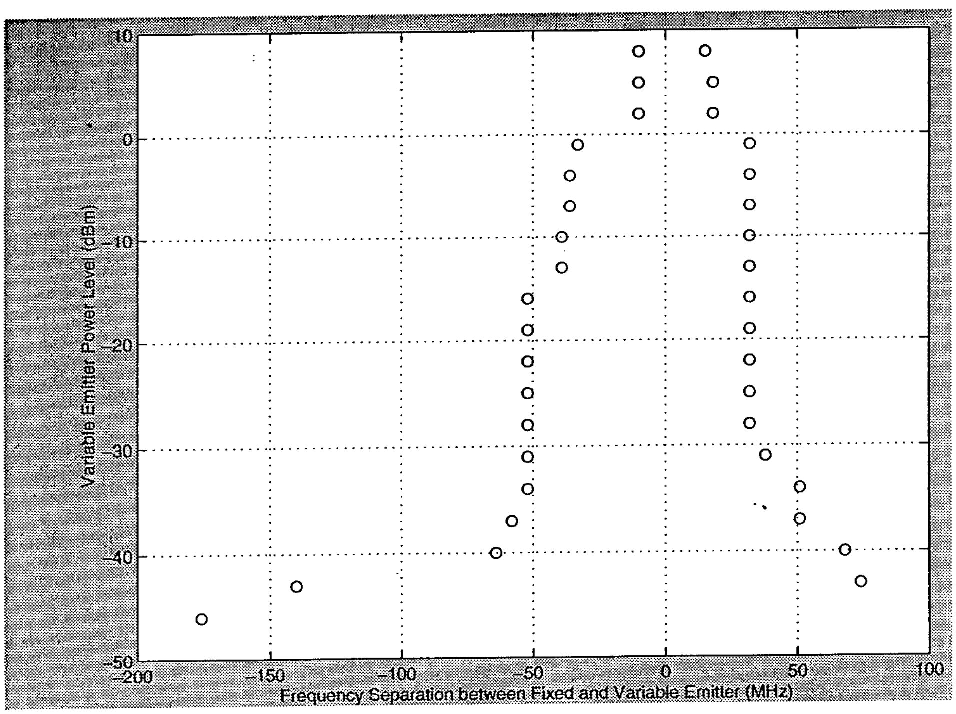

Fig. 4 — Power level vs fixed signal frequency as determined from Two-Tone Frequency Resolution Test data

2.7 Blocking Characteristics

The Blocking Test established the MSWC dual signal time resolution capability. Two test signals are applied to MSWC and the interval between respective leading edges was shortened. Initially, the two signals applied to the MSWC were offset by a maximum of 4 ms. This delay between signals was shortened successively to the minimum delay capability of the generator (Section 4.6 provides further details). MSWC reported both signals for delays between 3.95 ms and 10 μs while the leading pulse signal was detected steadily over the entire delay cycle.

2.8 Desensitization Characteristics

The MSWC signal reception performance in the presence of a high power level, out-of-band signal was measured in the Desensitization Test. A desensitizing signal set 10 MHz below the lower band edge at maximum power (10 mW) was applied to MSWC along with a signal within the active bandwidth set at the previously measured sensitivity power level (Section 4.7 provides further details). Desensitization reduced the probability of detection for two thirds of the channels to zero at the nominal sensitivity signal input power level. Signals in the other third of the channels were desensitized to a probability of detection between 0% and 100%.

2.9 Resolution Characteristics

The Simultaneous Emitter Test measured the MSWC dual copulse signal resolution for various pulse width/pulse repetition interval combinations. In this test, one emitter is applied at the channelizer center frequency while the other steps through the full bandwidth. Both signals are set at a power level of 4 dB above the sensitivity power level determined earlier (Section 4.8 provides further details). The MSWC detected both emitters reliably in one half of the PW/PRI combinations, but only detected both emitters at a probability near 50% for the remaining PW/PRI combinations.

2.10 CW Emitter Detection Characteristics

The CW Emitter Test measured the MSWC CW detection capability. This test has two parts: in the initial test, a single CW emitter is applied to the MSWC; in the second test, both a CW and a pulsed emitter are applied to the MSWC (Section 4.9 provides further details). The pulsed emitter steps through most of the active bandwidth at a power level 4 dB above the sensitivity level. MSWC was observed to receive the CW emitter with high probability when it was 8the sole signal applied to the channelizer. With both emitters applied, the MSWC received both emitters with high probability until they occurred within the same channel band. In this case, MSWC reliably reported the pulsed emitter while the CW emitter was not reported at all.

3. EQUIPMENT DESCRIPTION

The MSWC Receiver accepts signals over a wide instantaneous RF bandwidth. These signals are channelized and characterized into digital pulse descriptor words (PDWs) that quantify the signal amplitude, frequency, time of arrival (TOA), and pulse width (PW). The system design bandwidth is 2.0 GHz, spanning 3.0 to 5.0 GHz. The input RF signal power range spans -46 dBm to +10 dBm. Frequency is quantized to a 20 MHz channel, while the amplitude is quantized to 0.1 V_{REL}. TOA quantization of 10 ns is provided in the PDW, while PW quantization is 100 ns. Each intercepted signal is characterized with the data fields described above.

3.1 Equipment Layout

Figure 5 shows the MSWC equipment. The equipment is a brassboard for laboratory demonstration. The magnetostatic frequency demultiplexor is enclosed in a precision-machined housing with the MSWC circuits and the high permittivity permanent magnets. A single wideband 3.0 to 3.5 GHz RF port drives the MSWC Frequency Demultiplexor. Twenty-seven 20-MHz channel bandwidth RF output ports are provided on the MSWC Frequency Demultiplexor to drive the channelizer detector and log video amplifiers to transform the 50 dB input dynamic range to a reasonable signal processing range. The log video analog output drives the pulse descriptor encoder, which performs signal detection and qualification. The signal is then digitized and formatted for output transfer.

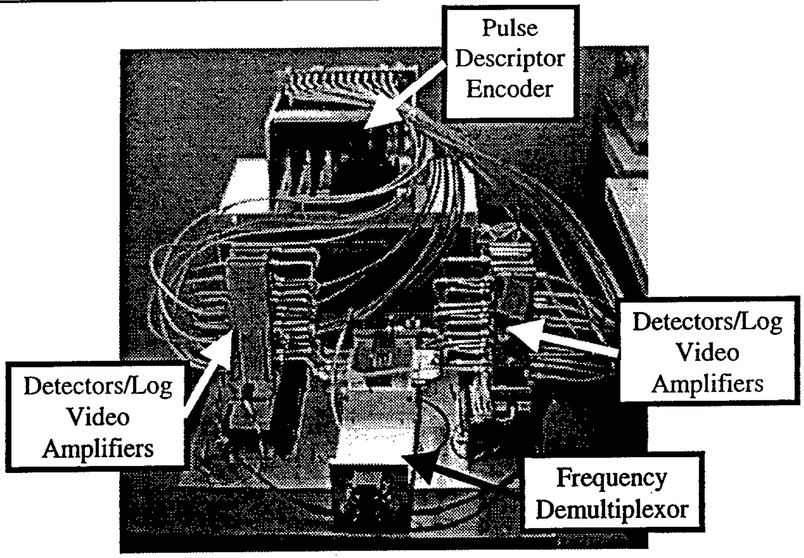

Fig. 5 — MSW Channelizer equipment

3.2 Receiver Architecture

As tested, the MSWC was a key element in receiver architecture, as indicated in Fig. 6. In this architecture, a channelized signal processing path was provided for signal acquisition, coarse parameter measurement, and analysis processing; an analysis signal processor was provided to precisely measure the signal.

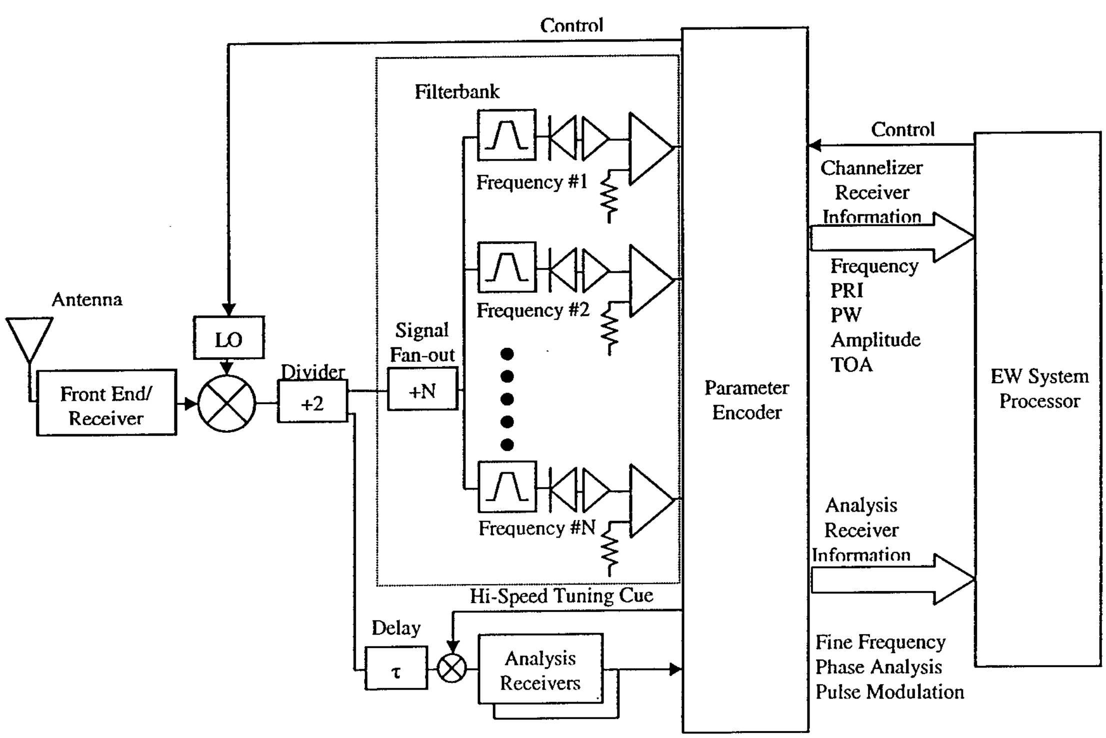

Fig. 6 — MSWC Receiver block diagram

3.3 Receiver Functional Description

The receiver antenna intercepts signals from the environment. A front-end/receiver protection functional element provides power limiting protection for the sensitive preamplifier and frequency conversion elements of the receiver. Environment signals are transmitted through the front-end/receiver protection circuits and converted into the 2.0 GHz wideband receiver IF that spans a frequency range from 3.0 to 5.0 GHz. The IF signal is divided into two ports, one driving the channelizer and the other driving the analysis processor.

The channelizer's frequency demultiplexor and encoder process the 2.0 GHz bandwidth IF in 500 MHz quarters of the entire bandwidth. The IF bandwidth is divided into quadrants and provided to respective MSWC elements. The channelizer encoder performs signal detection, logarithmic amplitude compression, and coarse signal measurement and provides the resulting descriptors for formatting. The coarse signal descriptors are incorporated into the composite receiver descriptor word for dissemination to the EW system signal sorting processor. In addition, the formatting circuit provides the coarse frequency descriptor of the signal to cue the Analysis Receiver.

The Analysis Receiver port is driven with the second output from the IF power divider. Coherent memory for the wideband IF environment processed in the channelizer is provided in the Analysis Receiver channel wideband delay line. The coherent memory provided by the delay line enables the Analysis Receiver to provide precise parametric measurements on the same pulse measured in the channelizer. The wideband delay line output is converted into the analysis channel IF frequency for subsequent precision parameter measurement. The analysis channel bandwidth is much narrower than the channelizer IF bandwidth to enable the required precision measurements with the currently available receiver signal parameter measurement elements. The Analysis Receiver tuning command is the coarse frequency descriptor provided by the channelizer. The Analysis Receiver includes precision signal measurement and encoding, and the precision signal descriptor generated in the Analysis Receiver is provided to the signal formatter for integration into the signal descriptor word. The composite signal descriptor is provided as an output to the EW system signal sorting processor.

Figure 6 shows the MSWC receiver block diagram. A signal is received through the antenna at left, demultiplexed, and characterized by the filterbank, the Analysis Receivers, and the parameter encoder. The parameter encoder then sends a digital PDW containing information characterizing the frequency, time of arrival, pulse width, and amplitude of the input frequency to the EW system processor.

The MSWC receiver filters, detects, and encodes incoming signals. More specifically, a received signal is power limited in the front end/receiver protection to prevent damage by high power radar signals (see Fig. 6). It is then divided, with one signal applied to a 25-channel filterbank and the other to Analysis Receivers. The filterbank signal is divided into multiple parts and filtered by contiguous frequency band filters. The channel electronics include a tuned bandpass filter, a buffer, and a log amplifier. The bandpass filter defines the frequency segments of each channel. Ideally, these segments are continuous, covering the entire bandwidth of operation. The output of the filterbank is applied to a parameter encoder, which also receives the output from the Analysis Receivers. The parameter encoder applies channelizer receiver data, frequency, PRI, PW, amplitude, signal time of arrival, Analysis Receiver data, fine frequency, phase analysis, and pulse modulation to the EW system processor in the form of a digital PDW.

3.4 Evaluation Equipment Functional Description

The MSWC equipment evaluated included a frequency demultiplexing filterbank with associated log amplifiers, a parameter encoder, and a pulse descriptor word interface processor. The MSWC frequency demultiplexor equipment spans the frequency range between 3.0 and 3.5 GHz, providing only a single quadrant of the design frequency coverage for evaluation. The frequency demultiplexing filterbank is based on magnetostatic wave technology. Each filter channel is implemented as a dual resonator MSW filter. The filter elements are driven by a single stripline that transfers frequency channel energy into the respective MSW filter through proximity coupling. Filter tuning to the frequency of interest is accomplished by using magnetic field biasing. Because high permittivity permanent magnets provide the magnetic field bias potential, the magnetic field applied to each filter is adjusted using the magnetic pole spacing.

The RF input test signal is applied to the 25-channel frequency demultiplexor filterbank. Signals proceed through the filterbank as explained above and amplified before being applied to the parameter encoder. The parameter encoder generates the digital PDW including frequency (5 bits), which is reported as channel number; amplitude (6 bits); pulse width (5 bits); and time of arrival (16 bits). The MSWC pulse descriptors are output through a first-in, first-out (FIFO) buffer to subsequent processing elements.

4. TEST ANALYSIS

The MSWC was evaluated to determine the level of performance achievable in EW applications. This section presents the results of the evaluation, where the analysis results are provided with the testing performed. The results are based on a comprehensive assembly and reduction of the data accumulated. Analysis of the reduced data is then provided to indicate the EW system impact of measured MSWC performance.

4.1 Sensitivity Test (Includes Information for Frequency Accuracy Test)

The Sensitivity Test measures the minimum power level at which the MSWC records all pulses applied. The test is performed over the entire bandwidth (3.0 to 3.5 GHz) at 1-MHz intervals. The power level is initially set at -60 dBm and increased by 1 dB until either all 10 pulses applied in a data sample are detected by the MSWC or the maximum power level of +10 dBm is reached. PDW measurement validity is based on the correlation of channel number, pulse time of arrival, and pulse period with the applied signal. Ten pulse-group sets of 10 pulses each drive the MSWC for each power level/frequency combination to ensure data accuracy. The total number of valid PDWs for all 10 runs is then divided by the total number of pulses provided (100 in this case) to find the average probability of intercept for the specified frequency/power level combination.

The MSWC was designed to provide a bandwidth of 20 MHz in each of its 25 channels, providing a total operational bandwidth of 500 MHz. The 25 MSWC channels cover a frequency range from 3.0 to 3.5 GHz. The design also indicated a linearity between the channel center frequency and the channel number.

The Sensitivity Test data show that not all 25 channels are functional nor do they respond in numeric frequency order (see Figs. 7 and 8). Channels 10 and 11, designed to cover the frequency range of 3.15 to 3.20 GHz, are not operating. Immediately prior to this spectral segment, channels 8 and 9 appear in reverse frequency order, as do the final two operating channels, 22 and 23. The two channels corresponding to the extremes of the spectral segment coverage, 0 and 24, are also nonfunctioning. A linear relationship exists between the measured channel center frequency and the channel number with a standard deviation of frequency error of 0.7972 MHz. In fact, the linear frequency relationship is only interrupted by the two missing channels, 10 and 11, and the two sections where channels are in reverse frequency order.

Figure 7 depicts the channel number as a function of applied input signal frequency. The center frequency of the channel responding is the abscissa while the channel number is the ordinate. These data were taken from the Sensitivity Test. The applied signal frequency spans the 3.0 to 3.5 GHz channelizer design bandwidth. The ordinate range, 1 to 25, indicates the MSWC channels that span the 3.0 to 3.5 GHz frequency coverage.

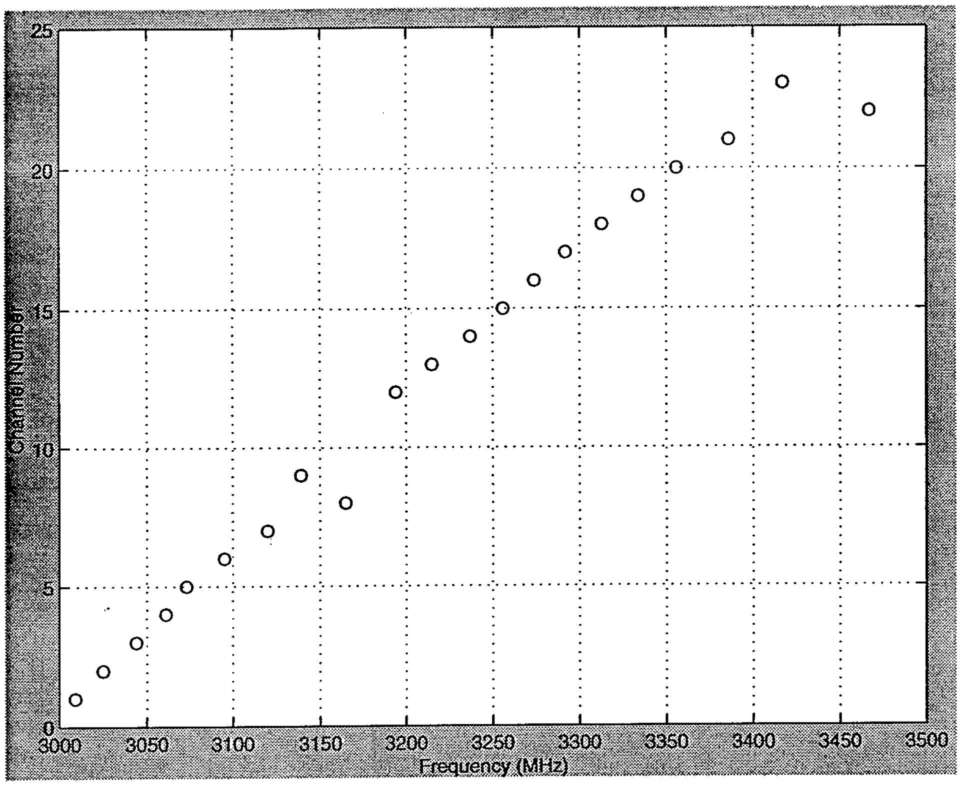

Fig. 7 — Channel number vs frequency

Figure 8 shows the sensitivity power level readings as a function of applied input signal frequency, which spans 3.0 to 3.5 GHz. Sensitivity power level fluctuations across the entire MSWC bandwidth are shown. The sensitivity power levels are centered about a nominal level of about -40 dBm across the frequency band. Spikes in the sensitivity power levels denote frequencies that fall between the MSWC channels. Voids can be discerned from 3.18 to 3.2 GHz (channel 9), 3.2 to 3.22 GHz (channel 10), 3.46 to 3.48 GHz (channel 23), and 3.48 to 3.5 GHz (channel 24).

The expected value of the sensitivity power level is -40.33 dBm with a standard deviation of 2.57 dB. The expected sensitivity is found by averaging the center frequency sensitivity power of each channel. Sensitivity power levels vs frequency data for a single channel are used to determine the channel center frequency, which is defined as the channel midpoint between the frequency with sensitivity 3 dB less than the channel maxima. The frequency interval between the channel 3 dB sensitivity points is the measured channel bandwidth. The average measured bandwidth is 16.086 MHz with standard deviation of 4.48 MHz (see Fig. 8).

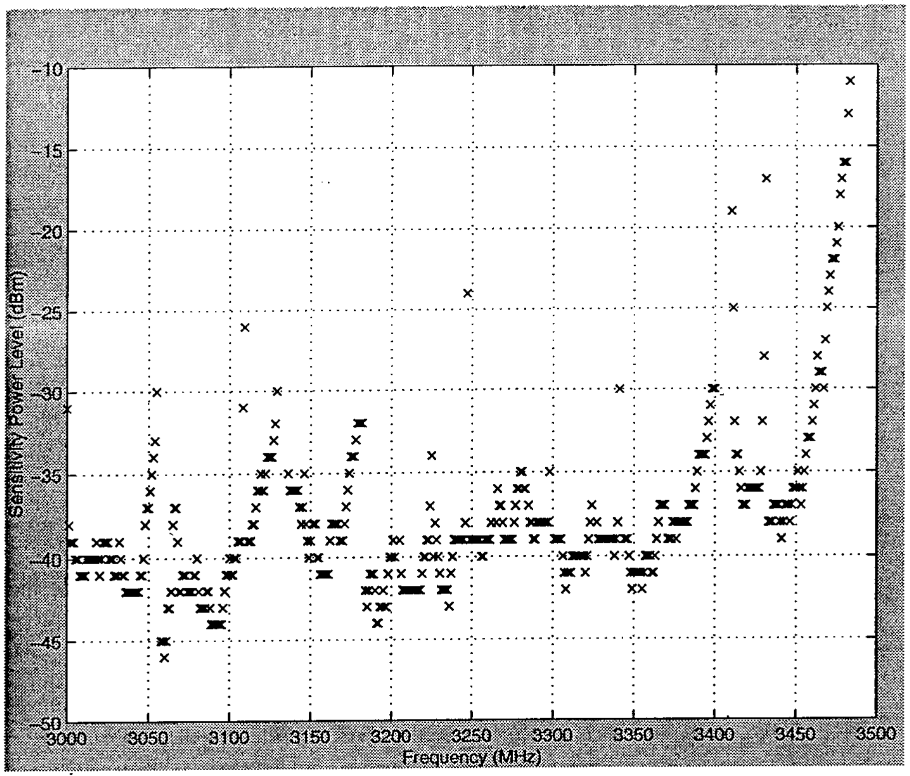

Fig. 8 — Sensitivity vs frequency

MSWC shows some sensitivity uniformity among channels, although certain channels have a much better response than others. Sensitivity fluctuations between channels are modest, as is indicated by a standard deviation of 2.57 dB. The sensitivity power levels range, however, from -36 dBm to -46 dBm, the most prevalent being -42 dBm, as shown in Fig. 8. Sensitivity fluctuations within a channel span a wide range. In channel 2, for example, the sensitivity power levels fluctuate inversely such that there is an inverted U-shape sensitivity curve and no well-defined center frequency. Channel 20, however, shows a well-defined center frequency and a channel bandwidth of 17.15 MHz, nearly the design bandwidth of 20 MHz.

Figure 9 shows the probability of intercept (POI) plotted vs the Sensitivity Power Level for the center frequencies of all 25 channels. The power level is the abscissa while the POI is the ordinate. It depicts the range over which all the channels begin receiving 100% of the pulses applied. The most sensitive channel reaches 100% POI at an input level of -46 dBm while the least sensitive doesn't reach 100% until -30 dBm is applied. The range in maximum POI is also shown in this figure. Some channels attain 100% POI while others never reach more than 80% POI. The MSWC POI characteristics generally exhibit a bivalued transfer function.

4.2 RF Power Test

The RF Power Test provides MSWC dynamic range data. The signal used in the Sensitivity Test, with a pulse repetition interval of 250 μs and pulse width of 2.2 μs, is applied to the MSWC in bursts of 10 pulses. The test signal power level is incremented from 3 dB below the MSWC sensitivity power level to a maximum level of 10 dBm at each frequency. Each power level is repeated 10 times to ensure data accuracy. Valid PDWs are identified using the same criteria used in the Sensitivity Test. The amplitudes are then averaged to determine the mean amplitude for the specified frequency and power level.

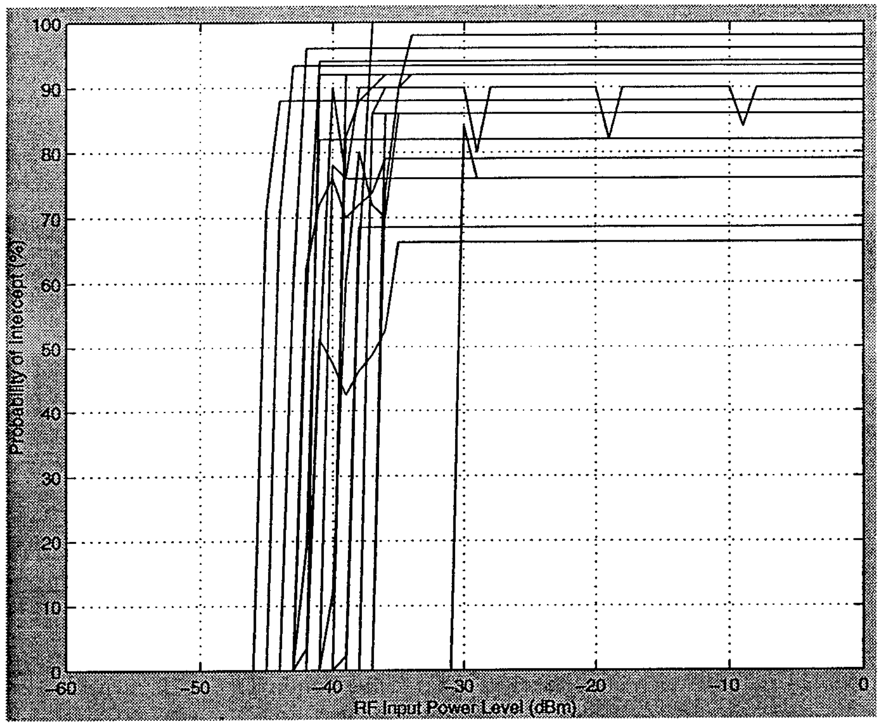

Fig. 9 — MSWC threshold performance

As is shown in Fig. 10, the average amplitude increases linearly with power for measurements at the channel center frequency. Output amplitude variations occur among channels as shown by the span of the output at each input power level. The MSWC was not observed to reach hard-limited saturation even near the maximum input power level. Some channels show output amplitudes that level off somewhat at higher power levels, but the slope of the transfer characteristic is positive for all RF Power Test data.

Figure 10 shows the MSWC transfer characteristic and the interchannel uniformity resulting from the RF Power Test data. A least-squares fit line was generated from all data for all channels retrieved in the RF Power Test. The standard error estimation of this line and the actual data range were then calculated and plotted over the least-squares fit line at an input power level increment of 10 dB. Note that the standard error is much smaller in the power level central operating range than at either input operating power range edge. The average amplitude also increases linearly with power level.

4.3 Pulse Rate Capability Test

The Pulse Rate Capability Test determines the MSWC's capability to detect shortened pulse repetition interval signals at various pulse widths. Thirteen signal combinations of pulse widths and PRIs are used at each of three different frequencies (3.174, 3.234, and 3.294 GHz). Each frequency is repeated 10 times to ensure data accuracy. PDW validity is determined using the same method as in the Sensitivity Test. The sum of valid PDWs for all 10 repetitions is then divided by the total number of pulses applied (five bursts per repetition) to find the average percentage of detected pulses.

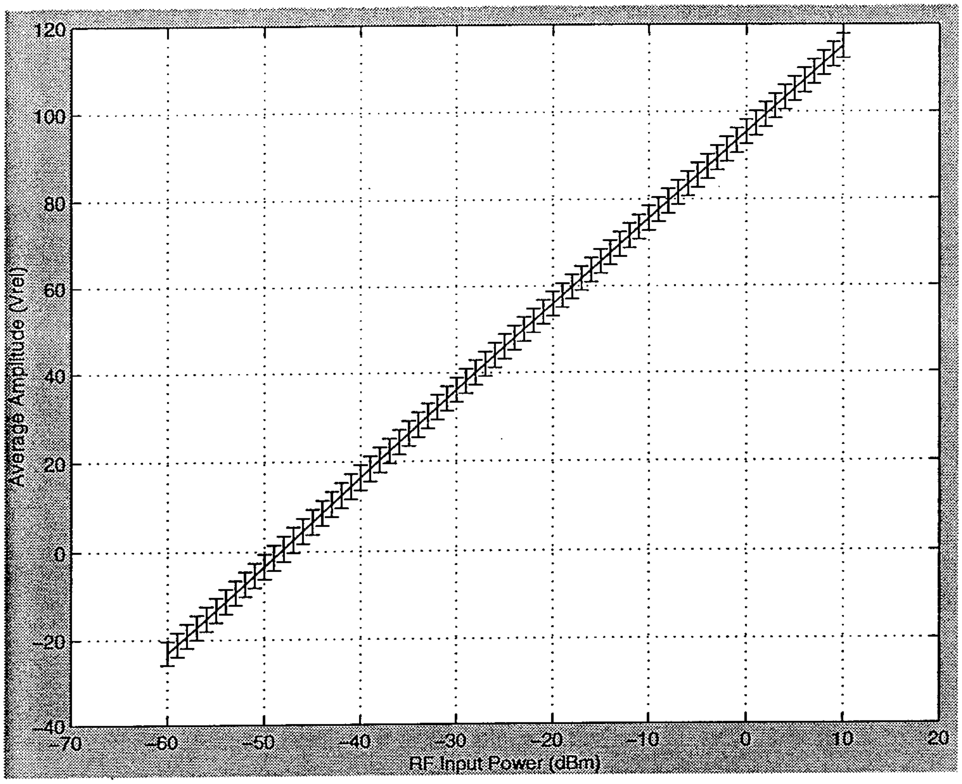

Fig. 10 — MSWC transfer characteristic and interchannel uniformity

Oddly, the MSWC shows higher probability of detection with smaller pulse widths and smaller pulse repetition intervals. The largest pulse width, 10 μs, is never received with a probability above 50%, if it is received at all. Also, pulses transmitted with a 1000 μs PRI show a low detection probability regardless of the pulse width. Pulses with the three smallest pulse widths (0.1, 0.5, and 1.0 μs), are received with a detection probability of only 60% for frequencies of 3.174 and 3.234 GHz (see Figs. 11 and 12). At a frequency of 3.294 GHz, 0.1 μs PW is received with a detection probability of only 22%, while the corresponding PW signals of 0.5 and 1.0 μs are received with a detection probability of 60%. The worst combination of signal parameters, 10 μs pulse width and 1000 μs PRI, yields a mere 50% probability of detection at a frequency of 3.174 GHz, and zero for frequencies of 3.234 and 3.294 GHz. Poor detection probabilities for large PW and PRI signals may be due to a limitation in the read-time of the MSWC since its maximum 6-ms read-time precludes detection of all pulses applied at a period of 1000 μs unless all of the pulses are coincident.

Figure 11 shows POI decreasing as the applied signal pulse width is increased. The specific data used were obtained with an applied frequency of 3.174 GHz. Each line on the plot represents data collected at different PRIs. Note that three of the four PRIs are reported with 100% POI for the lower pulse widths. The data corresponding to a PRI of 1000 μs are shown to have a maximum POI of 60%.

The remaining pulse width/pulse repetition interval combinations are detected with high probability, however. In fact, for the frequencies of 3.174 and 3.234 GHz, excluding the period of 1000 μs, nearly 100% of the transmitted pulses are received. The only exceptions are at PRIs of 100 μs and 10 μs, with a pulse width of 0.1 μs and a frequency of 3.234 GHz. In these cases, the probabilities of detection are approximately 95%. At 3.294 GHz, the pulse width of 0.1 μs is only detected with a 75% probability, while the signals of the other pulse widths are detected with a probability exceeding 90% (see Fig. 13).

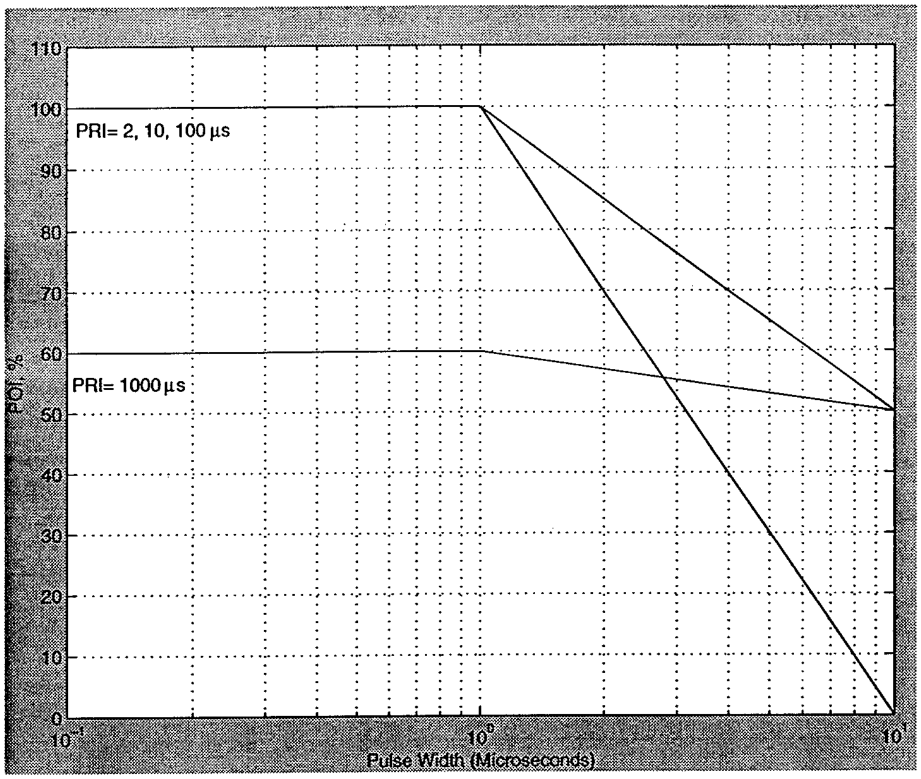

Fig. 11 — POI vs pulse width at 3.174 GHz

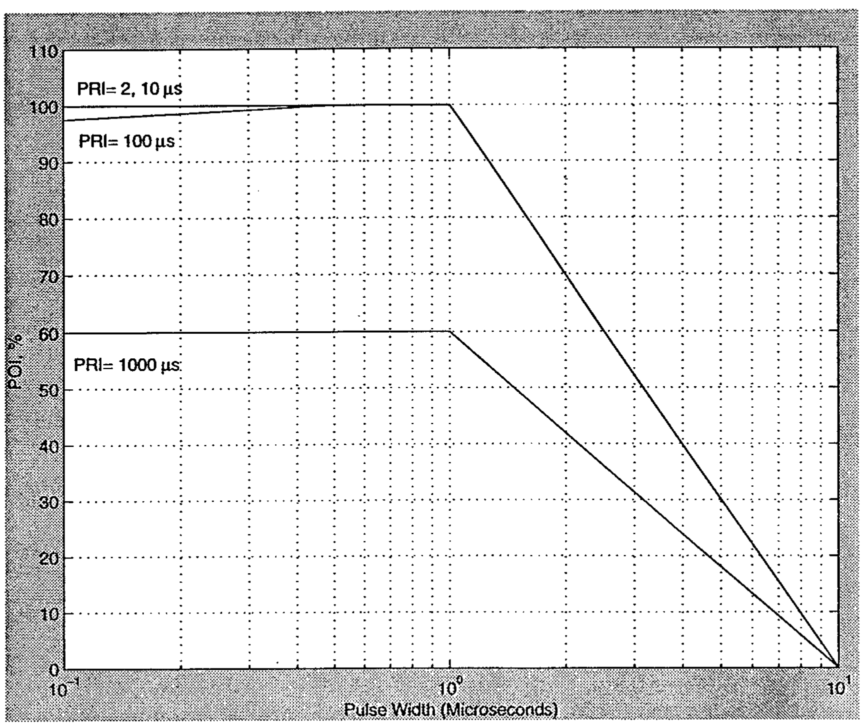

Fig. 12 — POI vs pulse width at 3.234 GHz

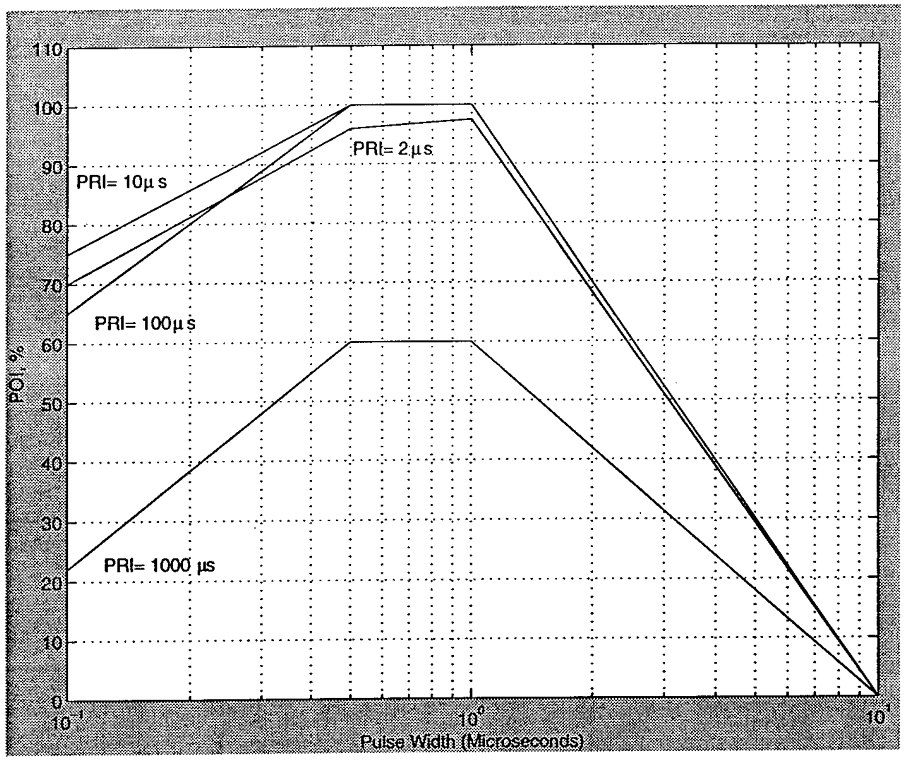

Fig. 13 — POI vs pulse width at 3.294 GHz

Figure 12 shows POI decreasing as the applied signal pulse width increases for an applied signal frequency of 3.234 GHz. This figure is similar to Fig. 11 except that the applied frequency is 3.234 GHz. Note that for PRIs of 2, 10, and 100 μs, the POI is at or near 100% until the pulse width reaches 10.0 μs. The same condition exists for an applied frequency of 3.174 GHz. Also, for a PRI of 1000 μs, both applied frequencies show a POI of 60% until the applied pulse width reaches the maximum of 10 μs. At this point, the applied frequency of 3.234 GHz does not receive the signal, while the 3.174 GHz applied frequency receives it at 50%.

Figure 13 shows POI decreasing as applied signal pulse width increases for an applied signal frequency of 3.294 GHz. For this frequency, the smallest pulse width as well as the largest pulse width are not received well, differing from the previous two figures. For a PRI of 1000 μs, the peak POI is the same as for the previous applied frequencies, 60%. The remaining three PRIs also peak at or near 100% POI, just as the previous two applied frequencies. This frequency differs in that all four PRIs are received at a lower percentage for the initial pulse width than for the middle pulse widths. It does, however, exhibit the same decline in POI as the previous applied signals as the pulse width increases to 10.0 μs.

4.4 Two-Tone Intermodulation Test

In the Intermodulation Test, two out-of-band signals are applied to the MSWC to determine intermodulation products occurring within the active bandwidth. Both signals are applied at frequencies above the MSWC upper band edge and are chosen to create a third-order product within the channelizer bandwidth. The test signal frequencies were varied to provide an intermodulation response in various MSWC channels, but responses were observed only from channels at the MSWC bandwidth edges. End-channel signals were detected regardless of the two frequencies applied, indicating that the measured response results from signal leakage through the channel filter and that intermodulation measurements are precluded by the level of channelizer channel selectivity provided.

4.5 Two-Tone Frequency Resolution Test

In the Two-Tone Frequency Resolution Test, the MSWC is evaluated to determine signal detection in the presence of a high-level, copulse interfering signal in the channelizer passband. The high-level signal is applied at 0 dBm, center frequency (3.234 GHz), while the second signal is applied at power levels ranging from the sensitivity power level of -46 dBm to the max power level (8 dBm) in 3 dB increments, over the entire frequency range. Measurements at each frequency are repeated 10 times to ensure data accuracy. Data are validated using the same method as was used in the Sensitivity Test. The total number of 50 pulses applied (five bursts for each repetition) is used to obtain an average probability of intercept.

Figure 14 depicts the MSWC empirical selectivity profile with detection power presented as a function of frequency difference from a maximum level emitter. A cutoff frequency was determined for each input power level as the closest frequency to the fixed emitter frequency received by the MSWC from the second emitter, both above and below the fixed emitter frequency. As the figure shows, the cutoff frequency approaches the fixed emitter frequency as the input power level is increased.

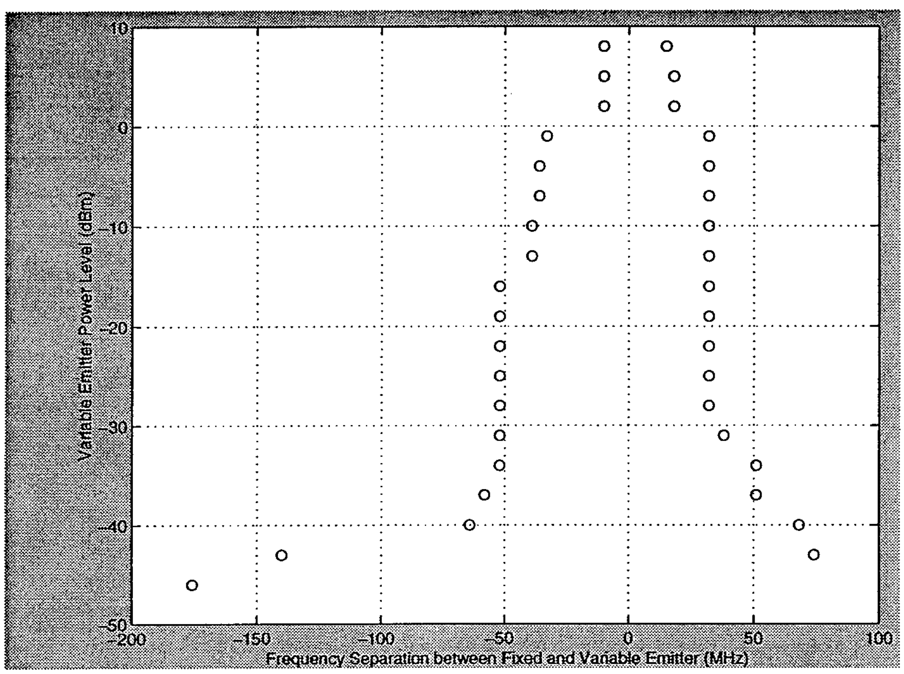

Fig. 14 — Two-Tone Frequency Resolution Test data

Figure 14 shows that the second emitter at low power levels can be totally blocked by the first emitter. As power is increased at the second emitter, pulses are detected on either side of the first emitter frequency. As the maximum power level is applied to the second emitter, a high probability of detection occurs over a wide portion of the channelizer spectral range extending to the channels adjacent to the first emitter frequency. Detections from Emitter 2 are observed to approach the center frequency of Emitter 1 as the power is increased. Figure 14 also shows that the MSWC detects Emitter 2 over several spectral segments at constant power levels.

4.6 Blocking Test

The Blocking Test determines the MSWC's ability to distinguish between pulses while the time between the pulse leading edges is shortened. Initially the delay between pulses is 4 ms. This is reduced by 100 ns until the delay is at the minimum generator capability of 65 ns. Only one burst is applied from each generator. This test is run twice, once with both emitters set at the center frequency (3.234 GHz) and once with Emitter 1 at the center frequency and Emitter 2 at 60 MHz above the center frequency. Valid PDWs from the first emitter (no delay) are determined in the same method as was used in the Sensitivity Test. Valid PDWs from the second emitter (delay) are also determined by the Sensitivity Test method, however the delay instead of the PRI is used in validating the TOA of the pulse.

The MSWC discerns two signals until the delay reaches the minimum of 65 ns (see Fig. 14) for both Emitter 2 frequency settings (3.234 and 3.294 GHz). At the minimum delay, neither signal is received. Between the maximum delay of 4 ms and a delay of 3960 μs at an Emitter 2 frequency setting of 3.234 GHz or 3940 μs at an Emitter 2 frequency setting of 3.294 GHz, the first emitter is reported steadily, but the second emitter is not detected. This observation occurred at both settings of the second emitter. The reduced detection probability at the large differential pulse delay may result from maximum MSWC read time limitations.

Figure 15 is a semi-log plot of the probability of intercept as a function of the delay between leading edges of synchronized pulses applied to the MSWC. The time delay range used extends from a minimum of 65 ns to a maximum of 4 ms. The MSWC receives both pulses at 100% POI for delays between 10 μs and 3950 μs.

4.7 Desensitization Test

The Desensitization Test measures MSWC sensitivity loss in the presence of high-power outband signals. One emitter is set at 10 MHz below the MSWC lower band edge, while the second emitter is incremented by 10 MHz from the lower band edge (3.0 GHz) to the center frequency (3.234 GHz). The power level for each frequency is set at its sensitivity power level determined earlier. Valid PDWs are determined under the same conditions used for the Sensitivity Test.

Desensitization measurements were made on approximately a third of the frequencies tested. Of this third, there was no pattern in the POI (see Fig. 15). Comparing the sensitivity of each channel in the presence of a desensitizing signal with the sensitivity measured without a desensitizing signal, we determined that desensitization consistently degrades MSWC sensitivity as expected. In one case, at a frequency of 3.150 GHz, the desensitized POI is higher than that of the normal sensitivity by 3 percentage points. The POI differences between the nondesensitized and desensitized measurements range from a minimum of 2% to a maximum of 45%. This difference appears to vary at random from frequency to frequency. Frequencies with the same baseline sensitivity (i.e., 3.08 and 3.20 GHz) can exhibit large POI differences (32% and 2%, respectively) in the presence of a desensitizing signal.

Figure 16 indicates the results of the signal frequency Desensitization Test. POI is plotted as the dependent variable with frequency of the applied inband signal as the independent variable. A large out-of-band signal that desensitizes the receiver to the inband signal is applied. If compared with the sensitivity power levels, it is noted that the desensitization signal lowers the MSWC system sensitivity.

4.8 Simultaneous Emitter Test

The Simultaneous Emitter Test measures the ability of the MSWC to distinguish two copulse signals at various pulse width/PRI combinations. One emitter is set at the MSWC center frequency (3.234 GHz), while the other steps through the full bandwidth. The power level is set 4 dB above the sensitivity power

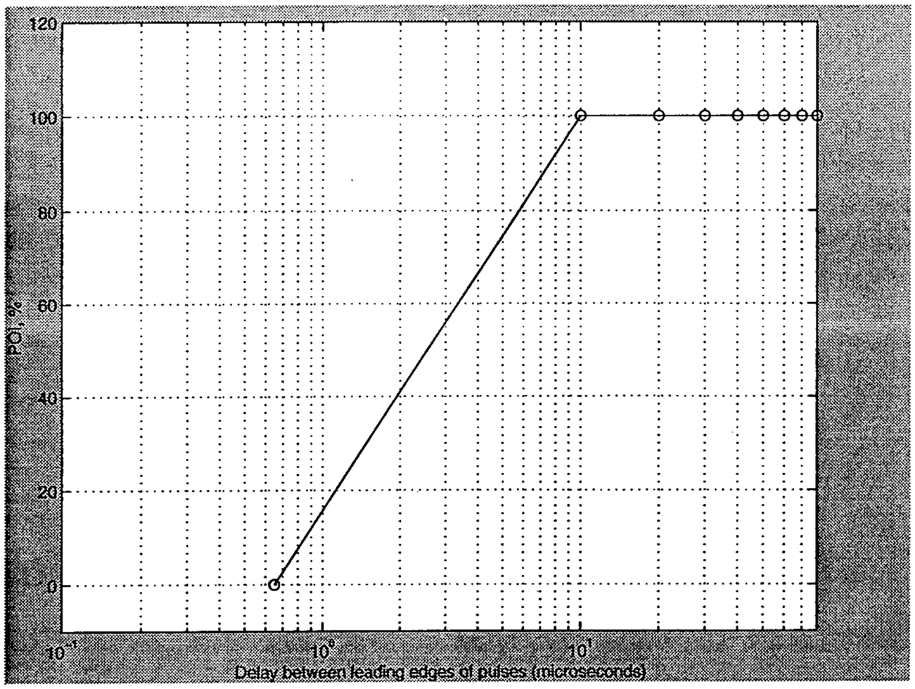

Fig. 15 — POI vs interfering signal delay

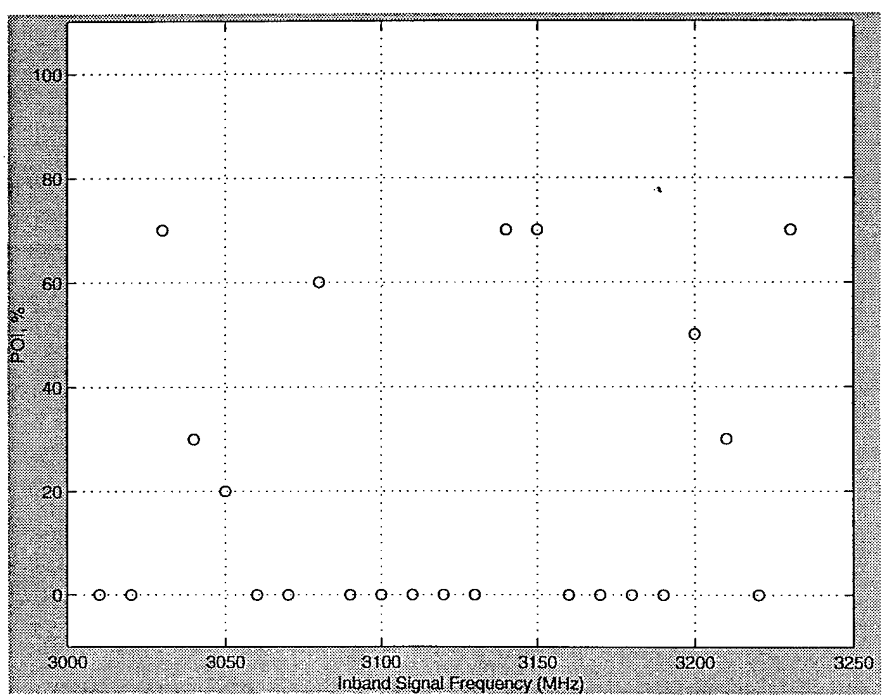

Fig. 16 — Signal frequency desensitization test

level of the emitter frequency. Valid PDWs are determined in the same method as was described in the Sensitivity Test. The MSWC detects both emitters for PRIs of 10 μs and 50 μs with 100% POI at all frequencies except when the first and second emitters are in the same frequency channel. As the second emitter crosses the first emitter's frequency, the POI decreases by 30% (see Table 3). The first emitter is not detected with high probability when the second emitter is within the same channel because of greater sensitivity at frequencies adjacent to the center frequency. For example, the sensitivity power level for 3.234 GHz is -42 dBm, while at 3.240 GHz, the power level is -39 dBm, causing the MSWC to detect the stronger signal when the two signals interfere. In the remaining two PRIs (20 μs and 100 μs), the MSWC POI ranges from 0% to 100%, although most have a probability above 50%. Only when the two emitters are in close frequency proximity is it clear that the second emitter is received with a higher probability. The MSWC exhibits a higher POI at a period of 100 μs than at 20 μs for Emitter 1, but there seems to be no such difference for the second emitter.

Table 3 — Simultaneous Emitters

	PW (μs)	PRI (μs)	Emitter 1 POI	Emitter 2 POI
Duty Cycle	Emitter 2 Freq. = 3.1 GHz (Emitter 1 set at 3.234 GHz)			
0.001	0.1	100	96	100
0.01	0.5	50	100	100
0.1	1.0	10	100	100
0.5	10.0	20	64	100
	Emitter 2 Freq. = 3.234 GHz (Emitter 1 set at 3.234 GHz)			
0.001	0.1	100	0	0
0.01	0.5	50	0	0
0.1	1.0	10	0	0.8
0.5	10.0	20	26.8	26

Table 3 presents multiple emitter MSWC POI performance. The table represents the change in emitter POI with emitters at different frequencies, or with emitters set at the same frequency. POI is measured for selected combinations of pulse width and pulse repetition intervals. When the emitters are at different frequencies, emitter POI decreases as the duty cycle increases, but the emitter POI rises as the duty cycle increases when the emitters are set at the same frequency.

At all frequencies for each PRI, Emitter 1 is not detected when Emitter 2 is in the same channel band. Note that Emitter 2 is not received with high probability. According to the data recorded, the periods of 50 μs and 10 μs are shown to have little variance in POI, but it is noted that Emitter 1 exhibits less variance across the frequency range than does Emitter 2 at these periods. Emitter 1 is received with a POI near 100% at all spectral locations except the center channel. With both emitters at the same frequency, the first emitter POI drops to 0% except for a duty cycle of 0.5, where it is received at 26.8%. Emitter 1 POI performance is not as defined at the 100 μs PRI as are the prior two PRIs (10 μs and 50 μs), but it follows the same pattern. At a PRI of 20 μs, however, Emitter 1 is received only with a probability of 70%, and the probability variation at the center channel is not as obvious. Emitter 2 exhibits a similar POI vs frequency characteristic as Emitter 1, but the spectral segments of zero POI near the center channel are not as defined. Also, at a PRI of 20 μs, Emitter 2 is detected at a POI of 100%, although there are sporadic POI measurements.

4.9 CW Emitter Test

The MSWC's capability for CW emitter reception is tested in the CW Emitter Test. The test consists of two segments: the first uses only a CW emitter and the second uses both a CW and a pulsed emitter. The pulsed emitter steps from 100 MHz below the center frequency to 100 MHz above, with a power level of 4 dB above the sensitivity power level reading. In both cases, the CW emitter frequency is set to the center of the bandwidth (3.234 GHz).

The MSWC receives the CW emitter with high probability even with interference. The few times the emitter isn't detected may be chance misreads since the test was not repeated to ensure data accuracy. Also, the few misreads are spaced throughout the frequency spectrum, indicating uniform MSWC performance across the operating spectrum.

When signals from both emitters are applied, the MSWC receives the CW emitter with high probability. The pulsed emitter is also received with high probability except when the CW emitter and pulsed emitter are within the same channel band. When a pulsed emitter and a CW emitter within the same channel band are introduced, the MSWC receives the CW emitter but not the pulsed emitter. In this test, also, there are some chance misreads. However, this may also be because the test was not repeated.

Figure 17 shows MSWC CW emitter detectability in the presence of pulse interference. The line plotted at a continuous 100% POI is the MSWC reception of the CW emitter without the pulsed emitter's presence. The other line shows the MSWC reception of CW emitter in the presence of the pulsed emitter. As shown, the MSWC does not receive the pulsed emitter when both emitters are within the same channel, but the CW emitter is received with 100% POI when it is in a different frequency channel than the pulsed emitter.

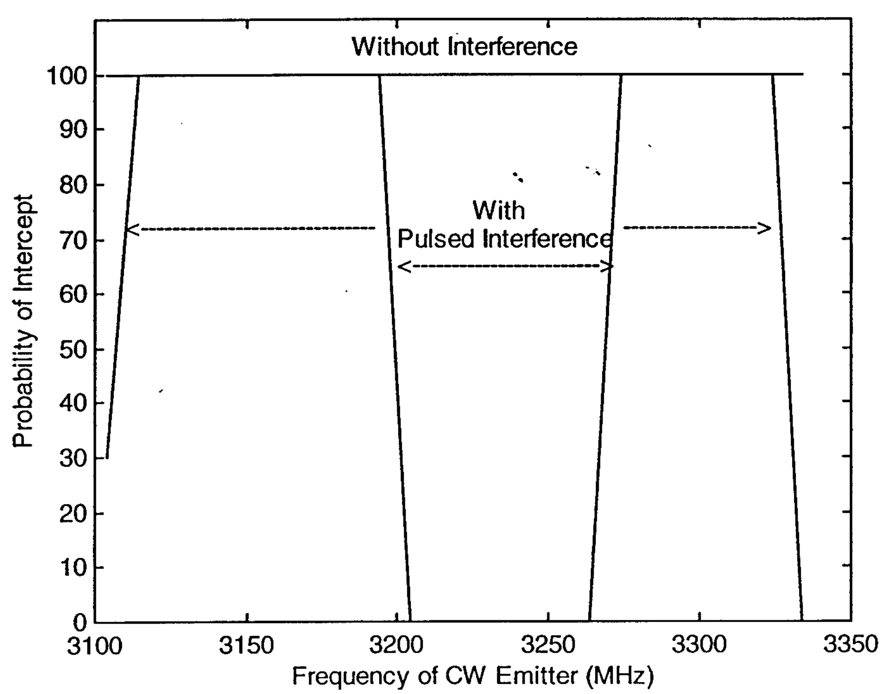

Fig. 17 — CW Emitter with pulsed emitter interference

5. CHARACTERIZATION TEST PLAN

5.1 Test Program

The sequence of tests described is used to characterize the MSWC utilizing a programmable synthesized test generator-based system approach (PTGS). Data collected by the MSWC processor's FIFO memory was transferred by custom cables under control of a PC input/output (I/O) card. These data are stored for later analysis. The number of pulses measured per test condition is 150. This will be limited to 15 pulses per collect time/FIFO due to the limitation of a Xilinx chip of the MSWC processor. The test conditions are recorded in a lab notebook while collect files also show test parameters. The power output from the test generators is level in a 500 MHz band and no further calibration equalization is required. Table 4 lists the tests used to evaluate the MSWC; they are described in detail in Sections 5.2 through 5.12.

Table 4 —Tests to be Performed

Test Number	Test to be Performed
1	Sensitivity
2	RF Power
3	Frequency Accuracy
4	System/Channel Bandwidth
5	Pulse Rate Capability
6	Two-Tone Frequency Resolution
7	Two-Tone Intermodulation Products
8	Blocking
9	Desensitization
10	Simultaneous Emitter
11	CW Emitter

Both single and dual frequency source tests were used to fully evaluate the unit under test. MSWC testing addresses performance under classical single-emitter reception operating conditions as well as for multiple signal reception afforded by the channelized architecture. These tests also evaluated MSWC performance in interfering environments.

5.1.1 Pulse-By-Pulse Test Facility

The test facility contains a control PC, one fully programmable test generator, another test generator or CW frequency source, two fully programmable digital pulse generators, and two microwave pulse modulators. Each of the two digital pulse generators modulates one test generator via each of two microwave pulse modulators. The IEEE 488 programmable nature of the test equipment allows full control of frequency and power level for the first generator as well as full control of pulse width and period for both. When the second generator is required, it is set in frequency and power as needed by that particular test and then modulated. The second generator never needs to change frequency or power and therefore does not need to be programmable.

Table 5 lists the equipment used in testing MSWC. Testing is performed using an IBM PC linked to the test equipment through a GPIB bus. Synthesized Sweep microwave generators are used in the test to generate the precision frequency RF signals and control power. The pulse generators modulate the synthesized sweep generators, providing accurate timing control and high off-state isolation.

5.1.2 Single-Source Test Configuration

Figure 18 diagrams the test equipment layout for all tests requiring only one RF generator and one pulse generator. These tests include the Sensitivity Test, the RF Power Test, and the Pulse Rate Capability Test. The processor is connected through GPIB cables to the pulse generator and the RF generator. The pulse generator drives the pulse modulator in the RF generators, and the RF generator output is applied to the input of the MSWC. An external trigger line from the MSWC electronics triggers the pulse generator. The MSWC electronics are connected through a differential-to-single-ended signal converter to the processor. The differential-to-single-ended signal converter is used to convert the PDW signal coming from the MSWC electronics to single-ended processor electronics.

Table 5 — PTGS Parameters Summary and Test Equipment

PTGS Parameters Summary: Parametric Coverage	
Frequency	0.01 — 20.0 GHz
Pulse Rate	1 — 10,000,000 pps
Amplitude	70 dB dynamic range
Pulse Width	0.1 — 100 μs
PTGS Parameter Summary: Parametric Resolution	
Frequency	1 kHz
Pulse Interval	2 μs
Amplitude	0.25 dB
Pulse Width	20 ns
Test Equipment	
(1) Pulse Generator	Model: HP8112A
(2) Pulse Generator	Model: HP8112A
(3) Synthesized Sweeper	Model: HP8340A
(4) Synthesized Sweeper	Model: HP83620A
(5) IBM PC	Model: IBM-386 (200 MB HDD space)
(6) Parallel I/O Card with two 48-pin cable connectors	Model: Cyrdio 96 (96-Channel TTL I/O Board)

5.2 Sensitivity Test

The Sensitivity Test determines the minimum power level signal detectable by the MSWC. Initially, the PTGS sensitivity will be set to a lower power (-60 dBm). At lower power levels, all pulses sent by the PTGS are not detectable by the MSWC. Pulse groups generated and provided to MSWC are repeated 10 times at each power level to ensure accuracy in data. A valid pulse detection is established if the modulus of the TOA and the period (250 μs) is within 30 μs of the 250 μs interval and is separated by more than 5 μs from the previous pulse. The power is raised until all 10 pulses sent are detected by the MSWC, and the power level at which this detection level occurs is the measured MSWC sensitivity level. Sensitivity is measured at equally spaced frequencies 1 MHz apart across the MSWC bandpass. The test emitter exhibits a pulse width of 2.2 μs and a PRI of 250 μs. The test sequence creates an emitter that changes frequency by 1 MHz every pulse from ± 300 MHz centered on the MSWC nominal bandpass center.

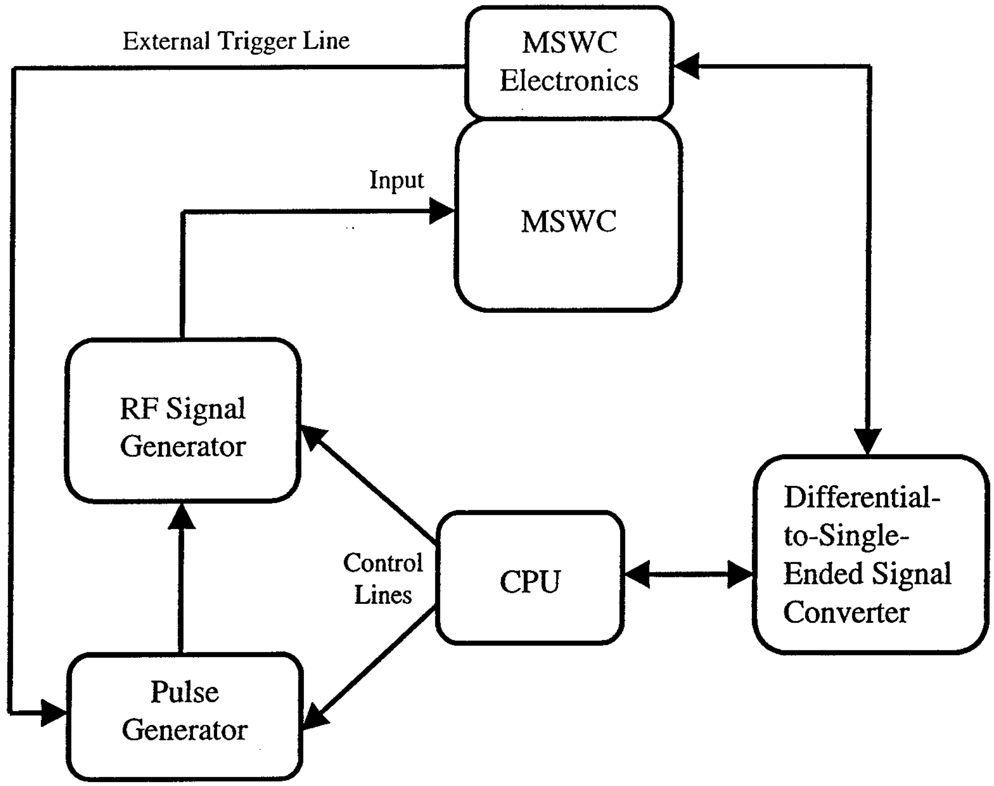

Fig. 18 — Test diagram with one pulse and one RF generator

Table 6 lists the specific settings for the RF generators and pulse generators that drive the MSWC during the Sensitivity Test. The frequency is variable, covering the entire operating bandwidth from 3.0 GHz to 3.5 GHz. The power level is also variable, running from a minimum of -60 dBm to a maximum of +10 dBm. The pulse generator is set at a constant 250 μs PRI and 2.2 μs PW. It is also set to send 10 pulses per generated signal to the MSWC.

Table 6 — Sensitivity Test Emitter

Frequency (GHz)	Variable
PRI (μs)	250
PW (μs)	2.2
Power (dBm)	Variable
Bursts	10

The Sensitivity Test flow diagram, Fig. 19, follows the processes performed by the Sensitivity Testing program. First, the serial port connected to the MSWC is initialized, as are the GPIB connections with the RF generator equipment. Then a dwell is sent to the MSWC (i.e., the applied pulses are sent to the input of the MSWC), and the computer checks for data and pulse descriptor words returned from the MSWC. If PDWs are available, the computer reads them, totals the number of pulses received, and records all data to predesignated output files. After each dwell, the number of repeated pulse groups transmitted is checked. If all 10 repetitions have not been completed, an additional dwell and data collect are initiated. If all repetitions have been completed, the total count of pulses received is divided by the total pulses applied and the answer is stored as the average POI for that frequency/power level combina-

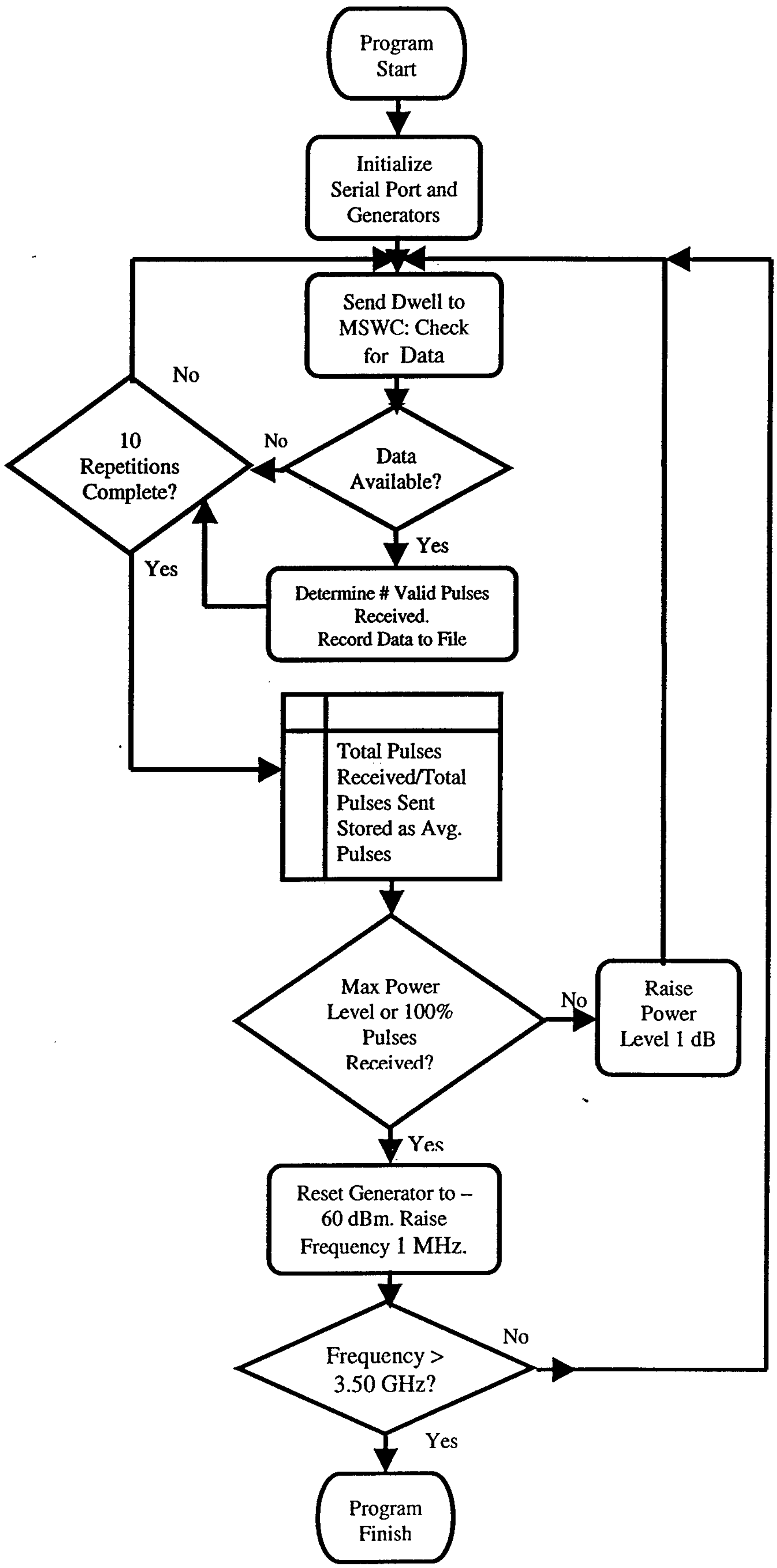

Fig. 19 — Sensitivity Test flow diagram

tion. If either all pulses applied were received or if the maximum power level of 10 dBm was reached, the generator frequency is increased by 1 MHz and reset to -60 dBm. If neither has occurred, the generator output power is increased by 1 dB, a dwell generated, and output data checked. If the new frequency is greater than the maximum frequency of 3.5 GHz, the program is complete; otherwise, additional dwells and data checks are generated.

5.3 RF Power Test

The RF Power Test empirically establishes the MSWC dynamic range. Using the sensitivity scenario (PRI = 250 µs, PW = 2.2 µs, 10 bursts), the emitter power increases in steps of 1 dB starting from 3 dB below the indicated sensitivity power to 4 dB above this level; then in 5 dB increments up to the maximum indicated safe MSWC input power level (+10 dBm).

Figure 20 follows the processes performed in the RF Power Test program. The serial port to the MSWC and GPIB connections to the RF generator are initialized. Next, the first frequency/sensitivity power combination is retrieved from memory, and the two loop boundary variables are set. The lower generator power boundary is set 3 dB below the sensitivity power and the upper boundary is set at 4 dB above the sensitivity power level. The generator is then set at the lower boundary power level. A dwell is sent, generating groups of pulses, and the computer checks for data output from the MSWC. If data are available, the number of valid pulses received is determined and all data are stored in an output file determined earlier. Next, the computer checks if the dwell count at the current frequency/power settings equals the programmed count. If it doesn't, another dwell and data checking sequence is initiated. If the prescribed dwell count has been completed, the current power level is compared with the upper bound set earlier. If the current level is less than the upper bound, the power is increased by 1 dB. If it is equal to or greater than the upper bound, it is increased by 5 dB. This power level is then checked to ensure it is less than the maximum power level of 10 dBm. If it is, the generator is set below 10 dBm, and additional dwell and data checking processes are performed. If the generator power is set equal to or greater than the max power, the next frequency/sensitivity power level combination is found and the new upper and lower loop boundaries are set. Finally, the new frequency is compared with the maximum frequency setting of 3.5 GHz to ensure that there are no more stored sensitivity readings. If the frequency setting is less than 3.5 GHz, the pulse group dwell and data across processes are repeated; otherwise, the program is completed.

5.4 Frequency Accuracy Test

The Frequency Accuracy Test is determined with Sensitivity Test and Pulse Rate Capability Test data. Both data sets are used to provide a more complete picture of the frequency accuracy as a function of frequency pulse width and pulse repetition interval.

5.5 System/Channel Bandwidth Test

System/Channel Bandwidth evaluation is performed using Sensitivity Test data. A comparison of the PTGS frequency with the MSWC channel number, or the MSWC frequency with the received frequency provide the required data.

5.6 Pulse Rate Capability Test

The MSWC Pulse Rate Capability is evaluated using a pulse density test in which the PRI is progressively shortened to a minimum of 2 µs. Ten pulse groups of five pulses at each pulse width are generated and applied to MSWC. The signal power is sufficiently above the detection threshold so that detection of all pulses is expected. The percentage of correctly received pulses is recorded. These tests are performed at the MSWC nominal center frequency (CF) of 3.234 GHz and at 60 MHz on either side.

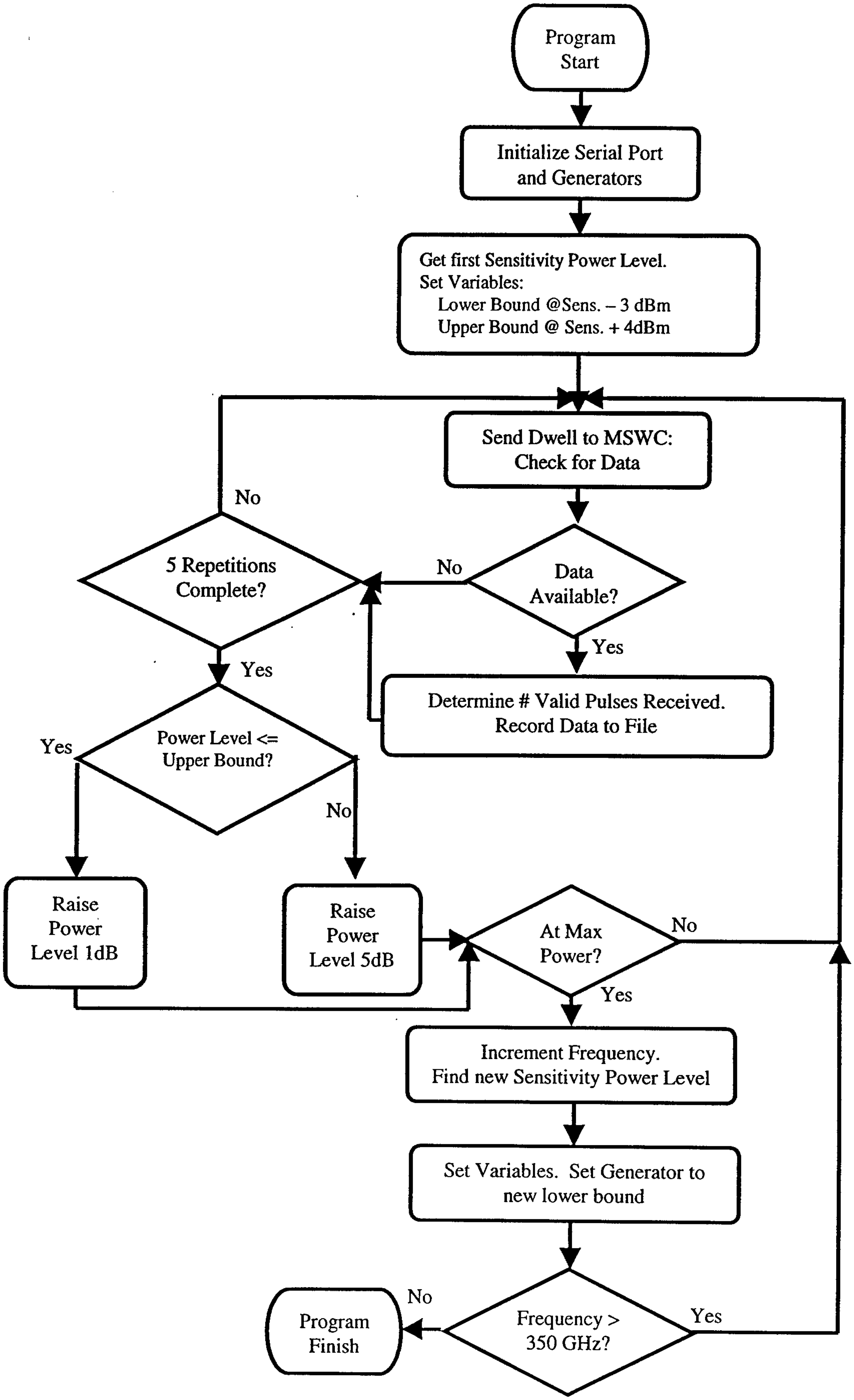

Fig. 20 — RF Power Test flow diagram

Table 7 shows the combinations of PRI and PW for the Pulse Rate Capability Test. For each PRI, the test cycles through the four pulse widths (0.1, 0.5, 1.0, 10.0 μs) before moving on to the next PRI. For example, at a PRI of 1000 μs, a signal is applied at pulse widths of 0.1, 0.5, 1.0, and 10.0 μs before moving on to the 100 μs PRI. Where an N/A is noted in the table, however, the specified pulse width is not used for the specified PRI because of length conflicts. For example, at a PRI of 2 μs, only pulse widths of 0.1, 0.5, and 1.0 μs are used.

Table 7 — PRC Test Scenario

PRI (μs)	PW=0.1 μs	PW=0.5 μs	PW=1 μs	PW=10 μs
1000	Tested	Tested	Tested	Tested
100	Tested	Tested	Tested	N/A
10	Tested	Tested	Tested	N/A
2	Tested	Tested	Tested	N/A

Figure 21 outlines the processes implemented during the Pulse Rate Capability Test program. The serial port of the MSWC and the GPIB connections with the RF generators are initialized. Next, the stored frequency/sensitivity power level combinations are searched to find the sensitivity power levels at the three test frequencies (3.174, 3.234, and 3.294 GHz). In Run 1, the two generators are set at the first and second frequencies and the power level for each is set at the respective sensitivity power level. In Run 2, the generators are set at the first and third frequencies and the power level for each is set at the respective sensitivity power level. The PRI of the pulse generators is successive, to the following: 1000 μs, 100 μs, 10 μs, and 2 μs. Next, the pulse generator pulse width is set, also in successive order, to one of the following: 0.1 μs, 0.5 μs, 1.0 μs, and 10.0 μs. A series of pulses is gated into the MSWC during a test dwell. MSWC output data is accessed and recorded in an output file. If all 10 test dwells haven't been completed, additional dwells are generated. If all the test dwells are completed, then pulse width generation status is assessed. If all the pulse width signals have not been provided to MSWC, additional test dwells are generated with the remaining signals. If pulse width test dwells are completed, PRI generator status is assessed. Again, if all the PRI test dwells have not been provided to the MSWC, the generator is set to the next PRI and additional test dwells are generated. If all PRI test dwells have been completed, the frequency generator status is assessed. Once all test dwells at the second frequency combination are completed, the MSWC Pulse Rate Capability Test data acquisition is completed.

5.7 Two-Tone Frequency Resolution Test

The Two-Tone Frequency Resolution Test requires two simultaneous signals. The first signal is at the nominal bandpass center. The other signal has a variable frequency that changes frequency by 1 MHz every pulse from ± 300 MHz centered on the MSWC nominal bandpass center. The variable frequency signal also has a variable power, which runs from the top of the MSWC full detection dynamic range to the minimum sensitivity in 3 dB increments. Table 8 provides other emitter parameters. This test requires two test generators; scenario frequencies are modified appropriately.

Table 8 — Two-Tone Frequency Resolution

	Emitter 1	Emitter 2
Frequency (GHz)	CF	Variable
PRI (μs)	1000	1000
PW (μs)	1.0	1.0
Power (dBm)	Max=0 dBm	Variable
Bursts	10	10

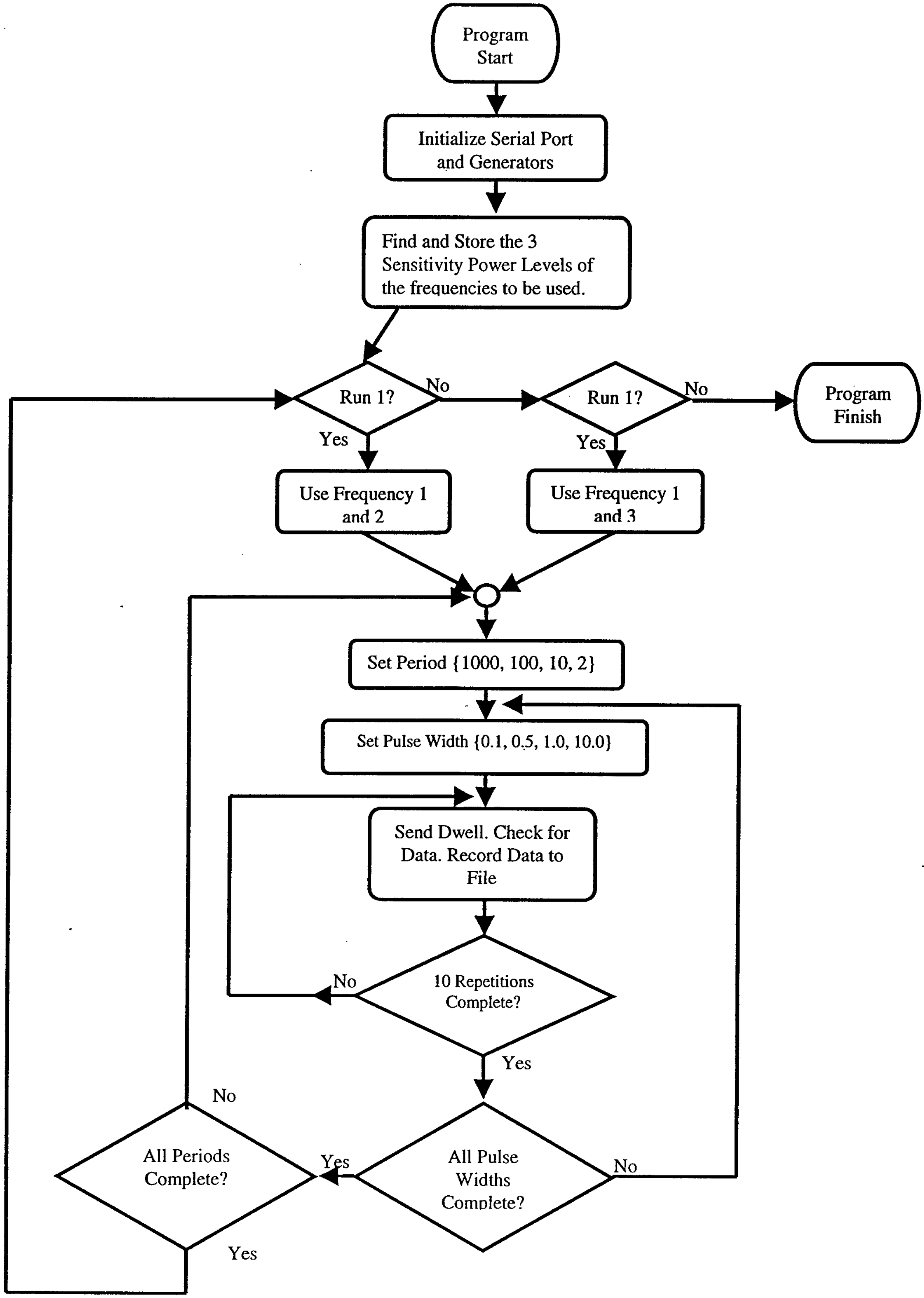

Fig. 21 — Pulse Rate Capability Test flow diagram

Table 8 shows the parameters of the RF generators and pulse generator for the Two-Tone Frequency Resolution Test. Emitter 1 is set at the center frequency (3.234 GHz) and at maximum power of 0 dBm, has a PRI of 1000 μs, a pulse width of 1.0 μs, and sends 10 pulses in an applied signal. Emitter 2 steps through in 1 MHz steps from 300 MHz below the center frequency to 300 MHz above the center frequency. It has the same PRI, PW, and burst setting as the first emitter, but the power level is also variable. The power is initially set at the minimum sensitivity reading (-46 dBm) and is incremented in 3 dB steps to the maximum power of +10 dBm.

Figure 22 shows the test equipment layout for all tests requiring two RF generators but only one pulse generator (copulsed signals). These tests include the Two-Tone Frequency Resolution Test, Two-Tone Frequency Modulation Test, Desensitization Test, Simultaneous Emitter Test, and CW Emitter Test. The processor is connected through GPIB cables to the pulse generator and the two RF generators. The pulse generator drives the pulsed modulator in the RF generators, and the RF generator output is applied to the input of the MSWC. An external trigger line from the MSWC electronics triggers the pulse generator. The MSWC electronics are connected through a differential-to-single-ended signal converter to the processor. The differential-to-single-ended signal converter is used to convert the PDW signal coming from the MSWC electronics to single-ended processor electronics.

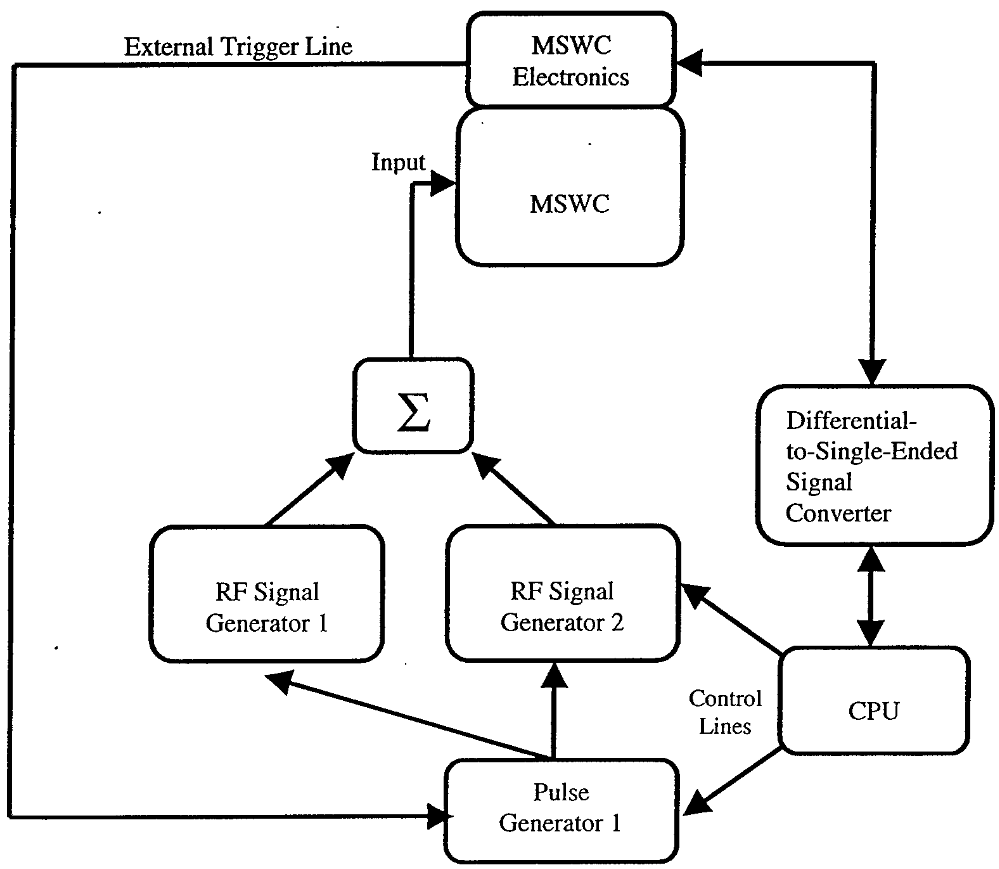

Fig. 22 — Test diagram with one pulse generator and two RF generators

Figure 23 diagrams the Two-Tone Frequency Resolution Test. The testing sequence begins with initialization of the serial port to the MSWC and the GPIB connections to the RF generators. Next, the first generator is set at the center frequency (3.234 GHz) and maximum power (0 dBm), and the second generator is set at the lower band edge frequency (3.0 GHz) and sensitivity power from prior measurement. The test signals are generated, applied to the MSWC, and data are retrieved. If MSWC has detected the applied signal, the number of valid received pulses is calculated and all data are recorded in an output file. The status of test signal dwells is assessed. If all 10 test dwells haven't been completed, an

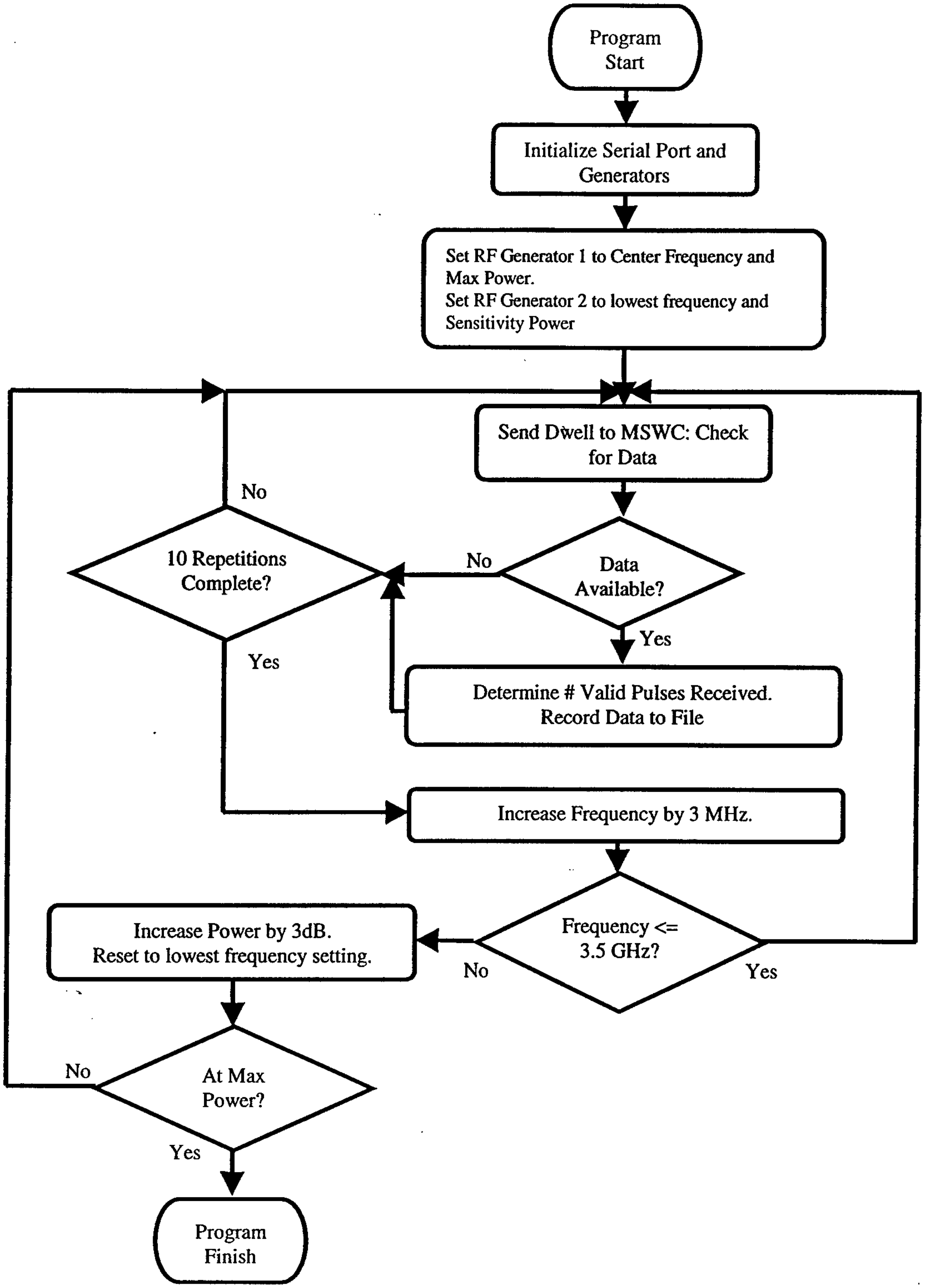

Fig. 23 — Two-Tone Frequency Resolution Test flow diagram

additional test dwell is generated. If all test dwells at the current frequency have been generated, the frequency is incremented by 3 MHz and the new frequency is compared with the maximum frequency of 3.5 GHz. If the current frequency is less than the maximum, sensitivity power level pulses are applied to MSWC and data are assessed. If the current frequency is greater than maximum, the power level is increased by 3 dB and the frequency is reset to the beginning value. If the new power level is less than the maximum level of 10 dBm, additional pulses are applied to MSWC and the resulting data are assessed. When the maximum power level is reached or exceeded, the test is completed.

5.8 Two-Tone Intermodulation Products Test

The Two-Tone Intermodulation Products Test uses two pulse-coincident (simultaneous) synchronized signals outside the passband to generate inband intermodulation products. An intermodulation product at the upper band edge (UBE) of -100 MHz (detectable) and another at UBE +500 MHz (undetectable) are produced by two signals at UBE +100 MHz and UBE +300 MHz (both undetectable). Both test emitters have a PW of 1.0 μs, a PRI of 1000 μs, and are applied in 10 pulse bursts. This test is performed by varying the amplitude of the two signals. Both outband signals are applied to MSWC at equal power and the power is raised in 1 dB steps from the sensitivity power to a level that provides reliable intermodulation product acquisition. Since the intermodulation signal amplitude cannot be directly measured, the test concludes at the power level where the intermodulation product is reliably detected. The power at which the intermodulation product first appears is determined to the nearest decibel. The intermodulation signal strength at its first appearance is estimated as the sensitivity lower level. This test requires two test generators.

Figure 24 diagrams the Two-Tone Intermodulation Products program processes. First, the serial port to the MSWC and the GPIB connections to the RF generators are initialized. Next, the generators are set at the two frequencies chosen (above the upper band edge) and at a power level of -60 dBm. Pulses are applied to MSWC during a data dwell and MSWC output is acquired. If data are available, the number of valid received pulses is determined and all data are recorded in an output file. If no data are found, the computer causes the generator to send additional pulses to the MSWC until data are obtained. The power level is then incremented by 1 dB and compared with the maximum power level. If the current level is less than the maximum power level, additional signal is applied to MSWC in a data dwell. At the maximum RF power level, the test is complete.

5.9 Blocking Test

The Blocking Test requires that two noncoincident pulsed signals alternate pulses while their amplitude and the time between leading edges is varied. The minimum time delay required for the MSWC to resolve two pulses is measured. The two signals walk through each other's pulse trains in 100 ns increments so that the pulses are coincident every 150 pulse groups. There is an initial delay of 4 ms between the generators that decreases by 10 μs down to 650 ns. MSWC reports two separate signals so as to distinguish the pulses. When the MSWC can no longer distinguish between the pulses, a group of pulses occurs that MSWC calls one pulse, but that the PTGS generates as two pulses. The recovery time is found from

$$(TIME\ RESOLN)*(N-1)/2$$

where N is the number of unresolved pulses and the *TIME RESOLN* is the difference in PRIs of the two signals. The test is performed twice, once with Emitters 1 and 2, and again with Emitters 1 and 3. This test requires two test generators.

Table 9 shows the parameters of the pulse and RF generators driving the MSWC for the Blocking Test. In the first repetition of the test, Emitters 1 and 2 are used. Emitter 1 is set at the center frequency of the MSWC operating range at the corresponding sensitivity power pulse (4 dB). Emitter 2 is also set at the center frequency for this run. Both RF generators are run by a single pulse generator, which is set with a PRI of 0.1 μs, a PW of 3.0 μs, and one burst sent per applied signal. For the second run of the test, the pulse generator remains the same, but Emitters 1 and 3 are used. For this repetition, the first emitter is the same as noted above, but the second emitter is set at 60 MHz above the center frequency.

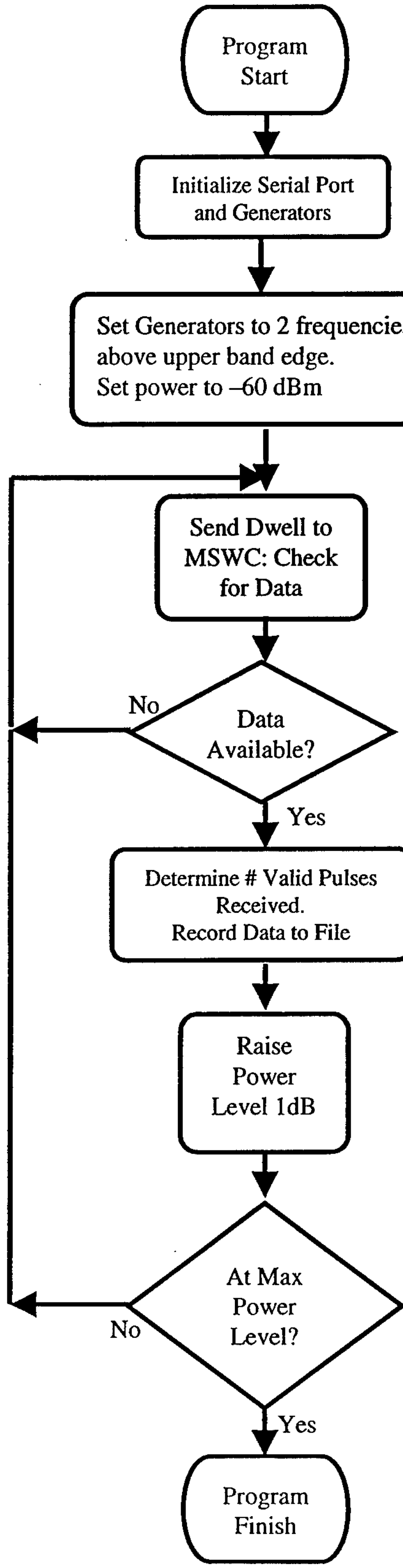

Fig. 24 — Two-Tone Intermodulation Products flow diagram

Table 9 — Blocking Test Emitters

	Emitter 1	Emitter 2	Emitter 3
Frequency (MHz)	CF	CF	CF + 60
PRI (μs)	0.1	0.1	0.1
PW (μs)	3.0	3.0	3.0
Power (dBm)	Sens + 4	Sens + 4	Sens + 4
Bursts	1	1	1

Figure 25 shows the test equipment layout for the Blocking Test, which requires two pulse generators and two RF generators. The processor is connected through GPIB cables to the two pulse generators and the two RF generators. The two pulse generators are connected to the pulse modulators of the RF generators, while the outputs of the two RF generators are summed and run to the input of the MSWC. An external trigger from the MSWC electronics triggers the pulse generators. The MSWC electronics drive a differential-to-single-ended signal converter interface to the processor. The MSWC-to-processor connection is two-way. The differential-to-single-ended signal converter is used to translate the PDW signal coming from the MSWC electronics to a single-ended signal the processor interface allows.

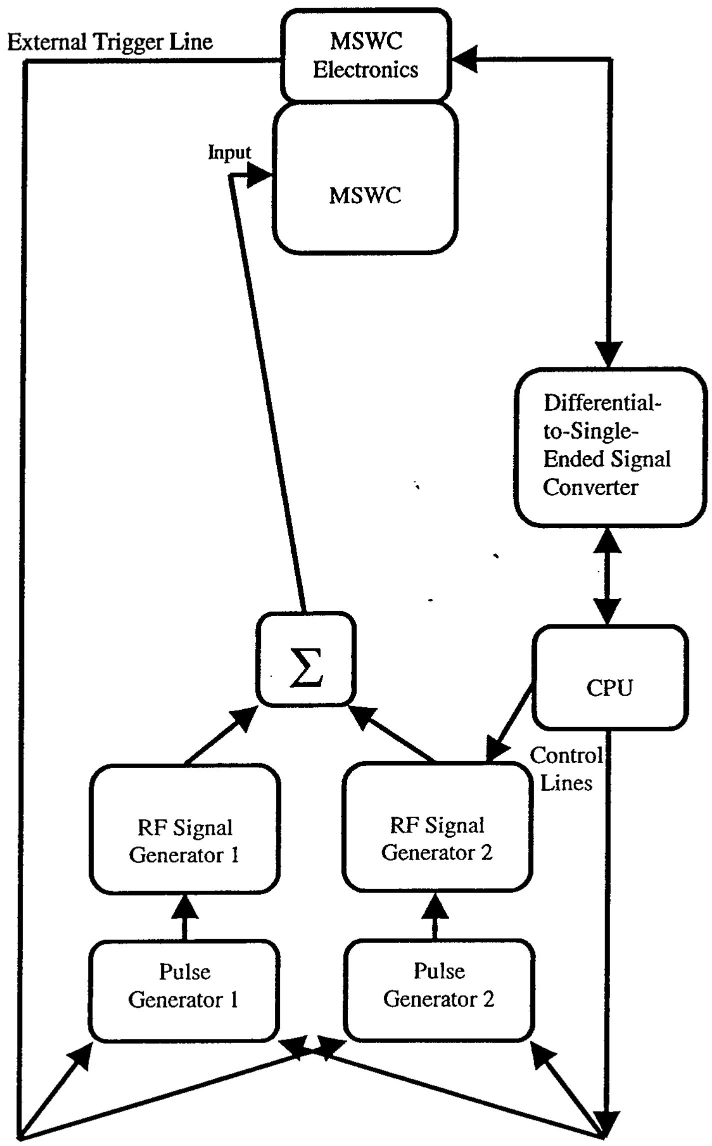

Fig. 25 —Test diagram with two pulse generators and two RF generators

Figure 26 diagrams the Blocking Test process. First, the serial port of the MSWC and the GPIB connections with the RF Signal Generators are initialized. Then, RF Signal Generator 1 is set at the MSWC center frequency and the signal power is set at a level 4 dB above the sensitivity power level. Pulse Generator 2 is set at a delay of 4 ms. For the first test run, RF Signal Generator 2 is set the same as RF Signal Generator 1. For the second test run, RF Signal Generator 2 is set 60 MHz above the MSWC center frequency and at a power level of 4 dB above the sensitivity power level at that frequency. After setting the generators, the signal is transmitted to the MSWC in a data dwell and available data are accessed. If data are available, the number of valid pulses received is determined and all data are recorded in an output file. Next, the delay on RF Signal Generator 2 is decreased by 10 µs and compared with the minimum delay of 65 ns. If the delay is greater than the minimum delay, additional data dwells are generated. If the delay is less than the minimum delay, run status is evaluated. If both runs are finished, the program is complete.

5.10 Desensitization Test

The Desensitization Test uses the emitters described in Table 10. This test measures the system sensitivity in the presence of large outband signals. The table gives the amplitude and distance from band edge of the outband signal during this test. This test requires simultaneous emitters: both the inband and outband signals must be pulse coincident. The outband signal parameters are identical to the inband signal parameters except as indicated in the table. This test requires two generators.

Table 10 — Desensitization Emitter Parameters

	Inband Emitter	Outband Emitter
Frequency (MHz)	Variable	LBE - 10 (see note)
PRI (µs)	250	250
PW (µs)	1.0	1.0
Power (dBm)	Sens	Max = 0 dBm
Bursts	10	10

Note: LBE = Lower Band Edge; Inband emitter frequencies (MHz) at LBE + 10, LBE + 15, LBE + 25, LBE + 45, LBE + 85,...etc. up to the center frequency

Table 10 lists the parameters used in the Desensitization Test. Both RF generators are driven by the same pulse generator, which is set at 250 µs PRI, 1.0 µs PW, sending 10 bursts per applied signal. One RF generator is set at 10 MHz below the lower band edge (3.0 GHz) at a maximum power of 0 dBm. The other RF generator is stepped through the operating band from 10 MHz above the lower band edge to the center frequency in 10 MHz steps. The power for this generator is set at the corresponding sensitivity power level as determined in the Sensitivity Test.

Figure 27 diagrams the Desensitization Test program. The process commences with the initialization of the serial port of the MSWC and the GPIB connections to the RF generators. The computer then sets the first generator to a frequency 10 MHz below the lower band edge (3.0 GHz) and maximum power (0 dBm), and the second generator at the frequency/sensitivity power level corresponding to a frequency at the lower band edge plus 10 MHz. Pulses are applied to MSWC in a data dwell and output data are assessed. If data are available, they are recorded in an output file. The second generator frequency is increased by 10 MHz and the power set to the sensitivity power level corresponding to this frequency. If the new Generator 2 frequency is less than the center frequency, a pulse dwell is generated. If the Generator 2 frequency is greater than the MSWC center frequency, the test is complete.

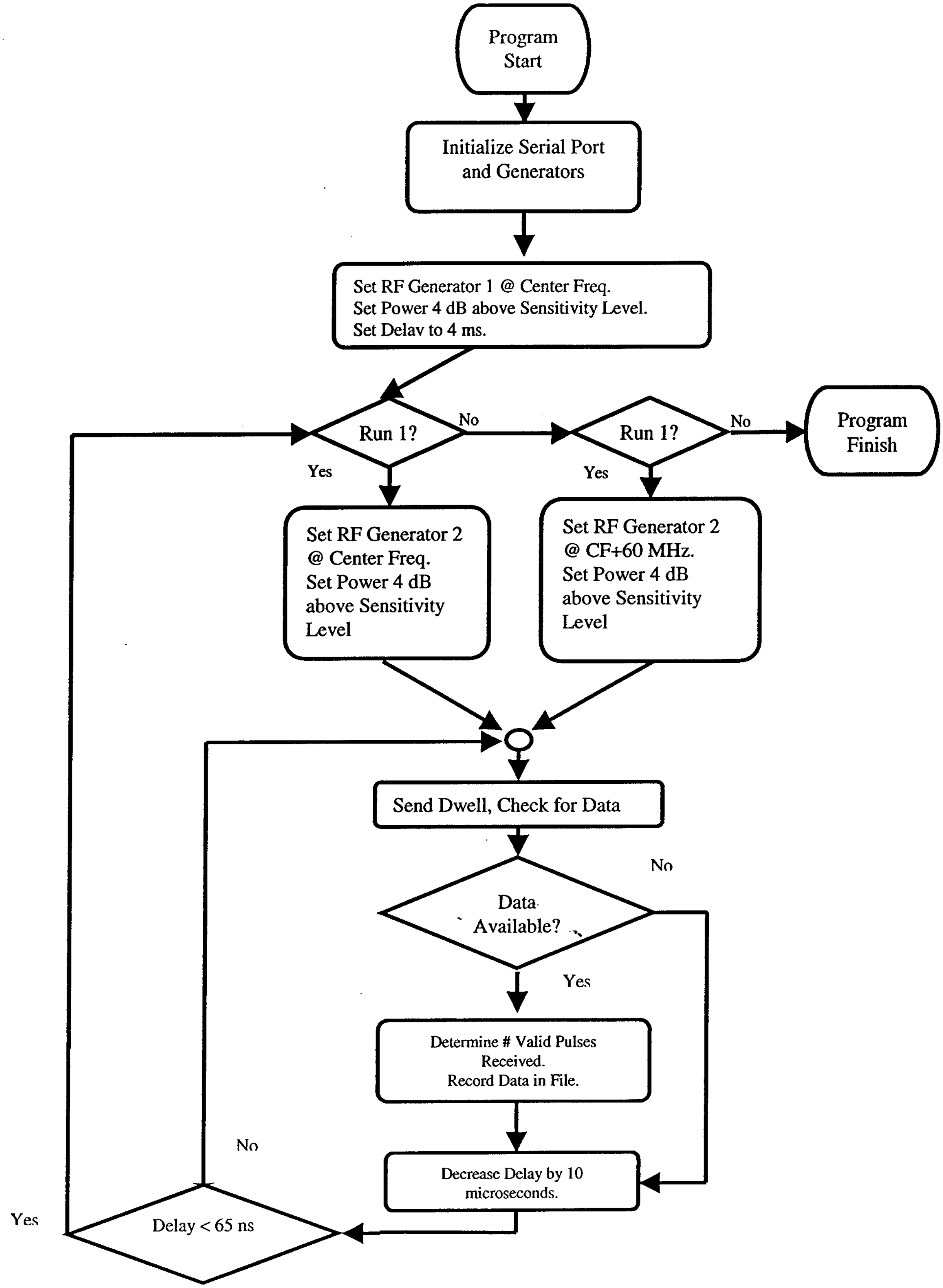

Fig. 26 — Blocking Test flow diagram

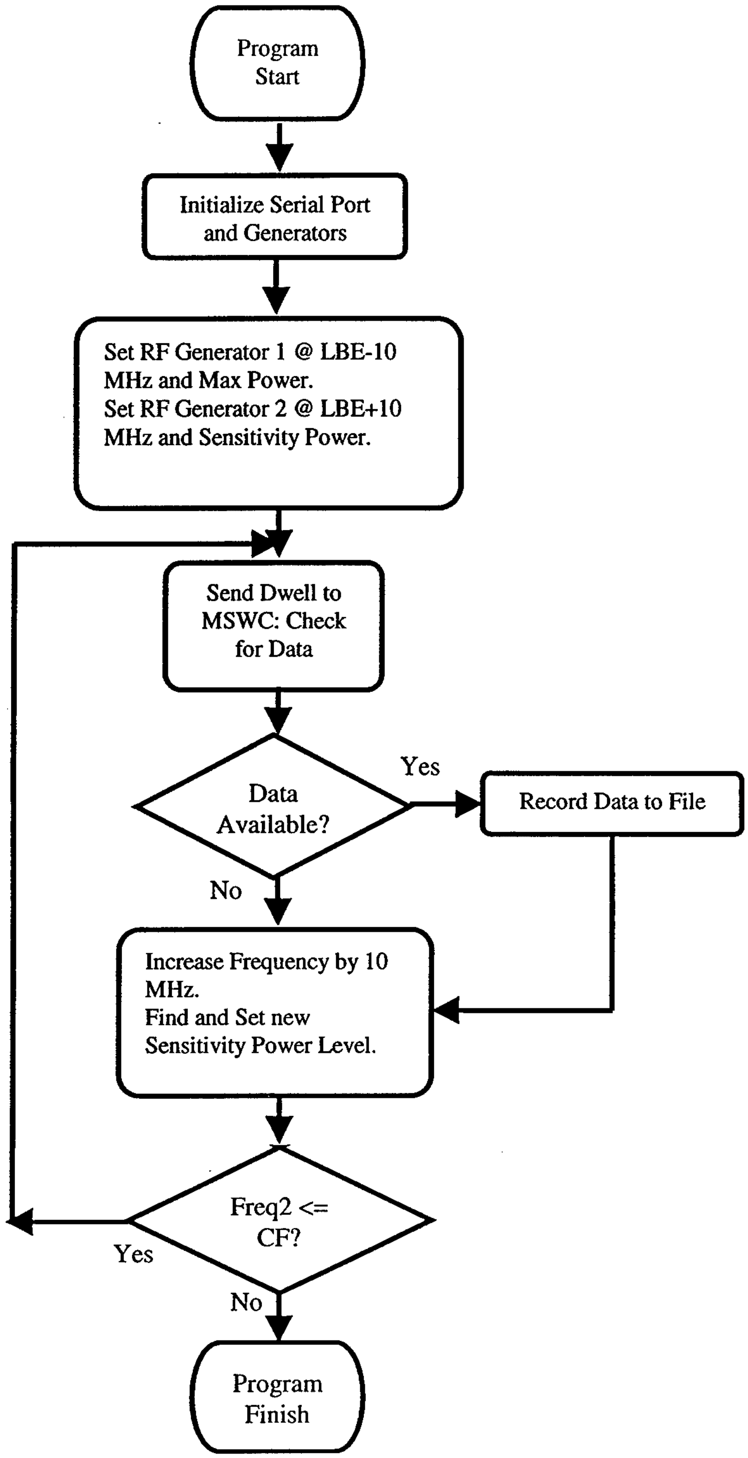

Fig. 27 — Desensitization Test flow diagram

5.11 Simultaneous Emitter Test

The Simultaneous Emitter Test requires two precisely synchronized (i.e., simultaneous) signals at various PRIs and PWs. Table 11 indicates the emitter pulse width and PRI parameter annotations for the two input signals, one of which is varied in frequency. The Emitter 1 frequency is set at the nominal bandpass center frequency, while Emitter 2 shifts frequency. Both emitters are provided at a power level 4 dB above the sensitivity power. This test is similar to the Two-Tone Frequency Resolution Test (Section 5.7) except that the PW and PRI of both emitters differ. Ten pulse bursts are provided to MSWC and five burst repetitions occur at each PW/PRI to ensure data accuracy. This test requires two test generators.

Table 11 — Simultaneous Emitter Scenario, Bursts = 10

PRI (μs)	PW=0.1 μs	PW=0.5 μs	PW=1.0 μs	PW=10 μs
100	Tested	N/A	N/A	N/A
50	N/A	Tested	N/A	N/A
10	N/A	N/A	Tested	N/A
20	N/A	N/A	N/A	Tested

Table 11 lists the settings for the pulse generators of the Simultaneous Emitter Test. In this test, each PRI is specifically matched to only one pulse width. For each applied frequency, the program cycles through four combinations of PRI/PW as shown in Table 11.

Figure 28 diagrams the Simultaneous Emitter Test processes, which commence with initialization of the serial port of the MSWC and the GPIB connections to the RF generators. Generator 1 is then set to the center frequency and its power level set 4 dB above the sensitivity power level. Generator 2 is set to the first frequency/sensitivity power level logged in the Sensitivity Test. A PRI/PW combination is selected and applied as signal modulation in successive order as shown in Table 11. Pulses are applied to MSWC in a data dwell and output data are assessed. If data are available, they are recorded in a file. An assessment of all repetitions for PRI/PW is made. If all dwells of PRI/PW haven't been provided to MSWC, additional data dwells are generated, and if they have been completed, an assessment of PRI/PW test signal transmission is performed. When all PRI/PW modulation combinations have been applied to MSWC, Generator 2 is set to the next frequency/sensitivity power level stored in memory. The generated signal is validated by ensuring that the frequency is less than the maximum frequency of 3.5 GHz. If the applied frequency is less than the maximum, the program continues applying pulses to MSWC. Otherwise, the test is complete.

5.12 CW Emitter Test

The CW Emitter Test assesses the MSWC performance capability against CW emitters. The emitters described in Table 12 are used in this test. This test consists of two parts: (1) a single CW emitter using Emitter 2, and (2) a two-emitter test with a CW and a pulsed emitter using both Emitters 1 and 2. The CW emitter is stepped in frequency by 10 MHz from 100 MHz below the center frequency to 100 MHz above the center frequency. This test requires two separate frequency channels.

Table 12 shows the parameters for the pulse and RF generators driving the MSWC in the CW Emitter Test. One RF generator is set at the MSWC center frequency with the corresponding sensitivity power level plus 4 dB. The other RF generator is set at 100 MHz below the center frequency and increased in each repetition by 10 MHz until it is 100 MHz above the center frequency. Only the pulsed emitter (Emitter 1) is driven by a pulse generator, which is set at 50 μs PRI and 0.5 μs PW, sending 10 bursts per signal.

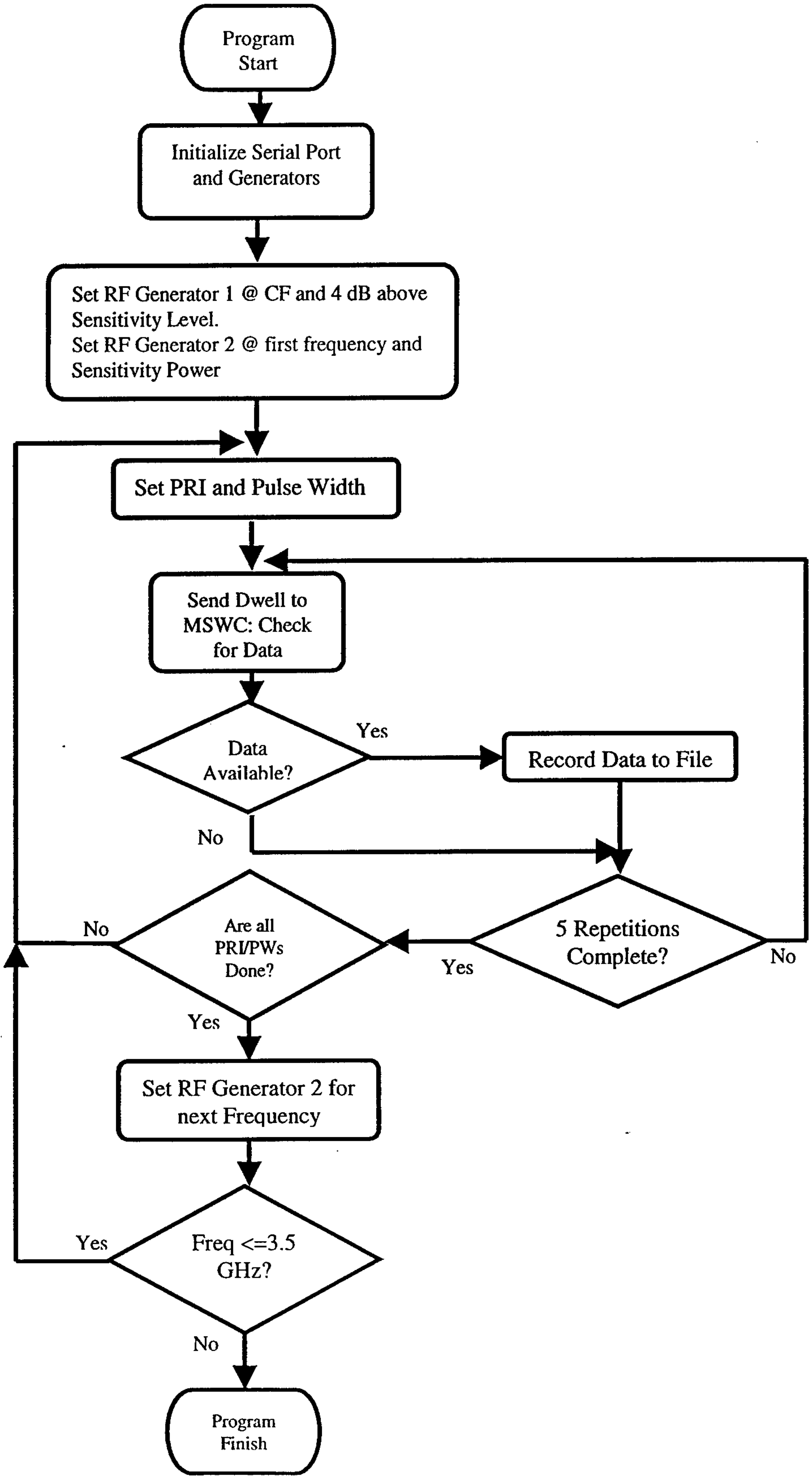

Fig. 28 — Simultaneous Emitter Test flow diagram

Table 12 — CW Emitter Test

	Emitter 1	Emitter 2	
Frequency (GHz)	CF	CF + 100	Interval = 10
PRI (μs)	50	CW	
PW (μs)	0.5	CW	
Power (dBm)	Sens + 4	Sens + 4	
Bursts	10		

Figure 29 diagrams the CW Emitter Test process. Initialization of the serial port to the MSWC and the GPIB connections to the RF generators begins the CW Emitter Test process. During the first run, the pulsed emitter is off and the CW emitter is set at the MSWC center frequency, at max power. For the second run, the pulsed emitter frequency is at 100 MHz below the MSWC center frequency at the sensitivity power level, and the CW emitter is set at the center frequency, at max power. A data dwell is then applied to the MSWC and output data are assessed. If data are available, they are recorded in an output file. The pulsed frequency is raised 10 MHz and the new sensitivity power level is set. If the Generator 2 frequency is less than 100 MHz above the center frequency, the program generates additional data dwells. If the Generator 2 frequency is more than 100 MHz above the MSWC center frequency and both runs of the program have been completed, the program is complete.

6. CONCLUSIONS AND RECOMMENDATIONS

The MSWC was subjected to a comprehensive array of controlled signal stimuli to provide an assessment of Magnetostatic Wave technology employed for frequency demultiplexing in an Electronic Warfare channelizer. Some significant progress is noted in bringing MSW frequency demultiplexor technology closer to practical implementation. Some of the potential advantages of MSW were evidenced in the data obtained during the course of this evaluation; other desirable channelizer characteristics appear to require additional technology evolution.

The MSWC as evaluated realized a physical implementation of thin-film deposited MSW material in a configuration to perform microwave frequency signal demultiplexing. The equipment provided a stable module for evaluation. Testing was performed over two months without failure and with negligible parametric variation.

Predicted MSW filter selectivity was verified in the evaluation program. The MSW demultiplexor filter design use a double-tuned coupled resonator equivalent circuit that was designed to reject spurious signals in the spectral side lobes with an attenuation of 24 dB per octave of bandwidth. As indicated in the Two-Tone Frequency Resolution evaluation, MSWC exhibits between 40 and 50 dB of spurious signal rejection as expected with a four-pole filter response.

The anticipated high dynamic range performance of the MSW demultiplexor was also demonstrated when dual copulse signals applied to the MSWC at a power level of 10 mW each did not produce measurable intermodulation response. Out-of-band signals were applied to produce inband channelizer spurious signal responses. The high level signal handling capability of MSWC indicates that in an EW system application, the IF amplifier driving the channelizer may be the determining element for the two-tone, third-order system response.

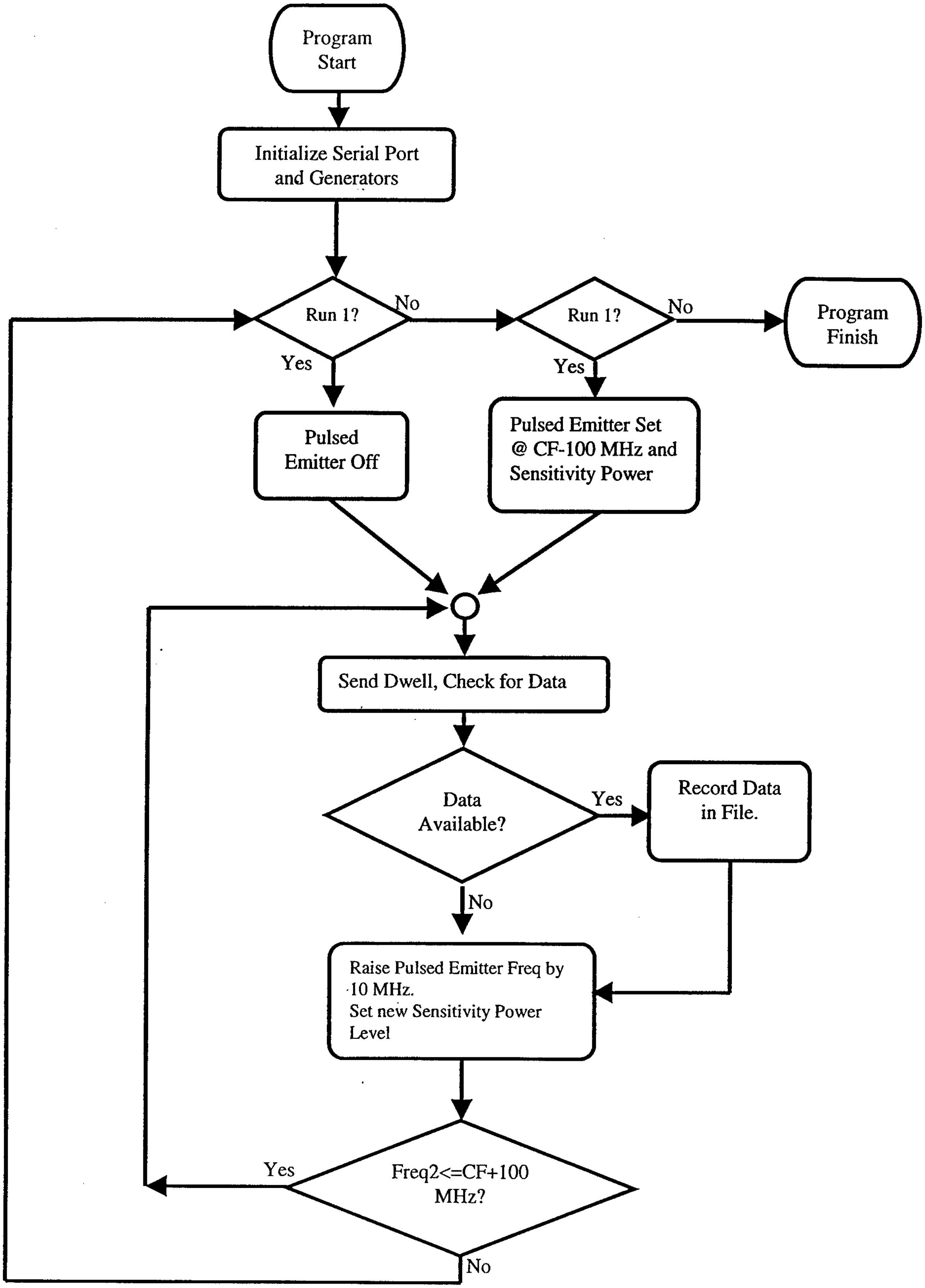

Fig. 29 — CW Emitter Test flow diagram

The development and evaluation of MSWC indicated that a number of challenges remain in the development of MSW for frequency demultiplexor and channelizer applications. A single frequency quadrant spanning 3.0 to 3.5 GHz was evaluated because of difficulty incurred in fabricating other frequency demultiplexor modules. In addition, channel center frequency linearity and channel bandwidth variances were also noted.

Magnetic field anomalies are among the technology issues that precluded full development of the MSW frequency demultiplexor modules. Size, weight, and power restrictions of channelizer module application require the use of permanent magnetic biasing. The gaps in the magnetic field were precision milled for the required magnetic filter tuning bias. In some cases, the resulting filter RF position in the band and the filter bandwidth were unacceptable.

Other evaluation observations also indicate that the MSWC fabrication process requires additional precision. Included in these observations were channels in reverse frequency order and substantial variation in channel bandwidth. These observations can also be attributed to magnetic field anomalies, but other issues such as MSW dimensional accuracy and MSW substrate placement within the module housing may be creating the observed channelizer performance.

The MSWC evaluation provides an assessment of the current status of this technology. The evaluation reinforced the concept feasibility. Also confirmed were some of the expected MSW technology attributes, including the high peak power handling and high dynamic range capability. MSWC implementation in a module configuration also indicated the level of product maturity. Here, significant materials and fabrication process controls require additional development before MSWC can be provided as an economical implementation for EW system application. Since observations indicate significant technology-based performance anomalies and shortfalls, efforts to upgrade the MSW technology base prior to product module development are recommended.

The evaluation-driven assessment indicates that additional MSW technology research is needed. Evaluation of permanent magnetic materials and their processing is recommended to assess the ability to control magnetic bias fields across the dimensions associated with MSWC demultiplexor filter banks. Corresponding developments could demonstrate the bias field control needed. In addition, MSW substrate implementation and processing developments are indicated to provide the selectivity and uniformity necessary for the MSWC.

Extending the channelizer frequency coverage to a full 2.0 GHz frequency bandwidth is needed. Also, additional MSW filter sections are recommended to increase filter selectivity. The demonstration of uniform channel bandwidths is needed to reflect that the technology issues of permanent magnet field control, as well as uniform MSW thin-film substrates, have been successfully addressed. Demonstration is also needed to successfully address missing channel and inverted frequency order channels observed in this evaluation. Considerable additional effort is required to advance the MSWC technology to the level of an EW systems applicable product. However, this effort has already demonstrated feasibility with consideration of EW system needs. Before significant efforts are expended in order to develop a feasible MSWC product, a thorough comparison between MSWC technology and digital receiver channelizers is recommended. This assessment should include such characteristics as performance, flexibility, and size. The MSWC technology evaluated represents a significant milestone in the development of MSW technology.